

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Condition Based vs. Time Based Maintenance

Case Study on Hypergolic Pumps

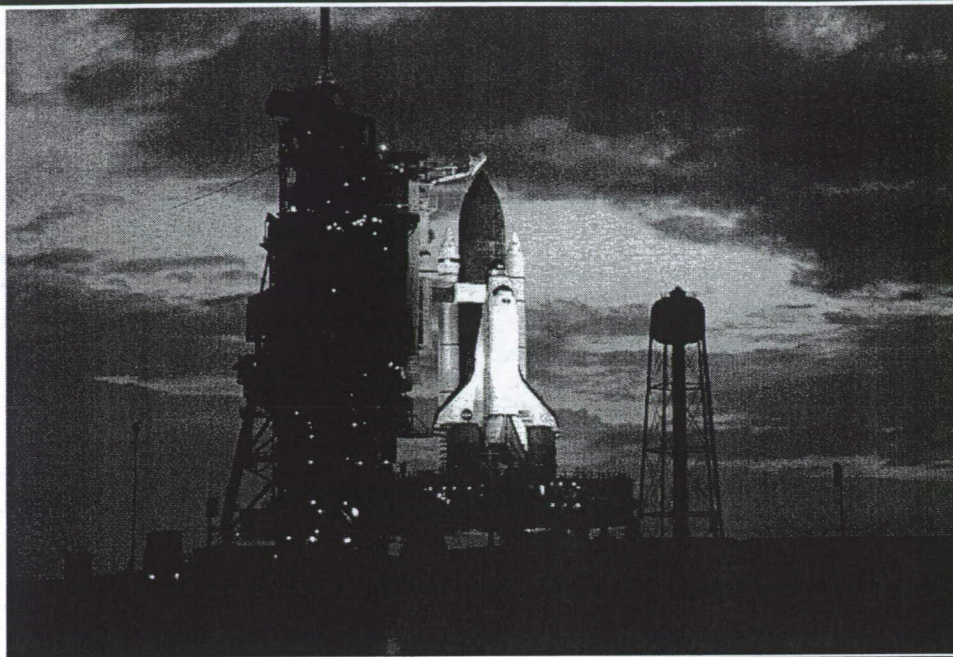
Lewis Gibson

August 2007

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NNU06VA01C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicity and display publicity, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



United Space Alliance (USA)



1



Image Credit: NASA

United Space Alliance (USA)

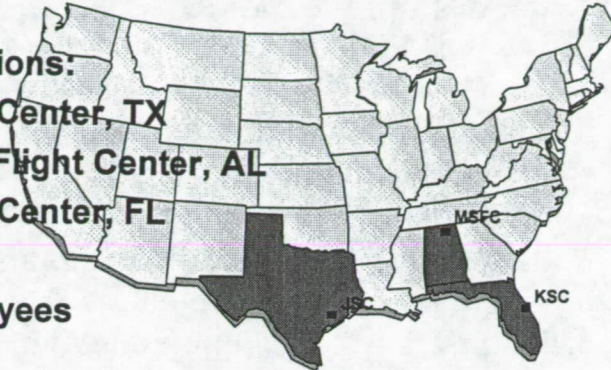
Who are we?

- NASA's primary industry partner in human space operations, including the Space Shuttle and the International Space Station.

- Three primary locations:

- Johnson Space Center, TX
- Marshall Space Flight Center, AL
- Kennedy Space Center, FL

- About 10,000 employees



Predictive Maintenance Engineering Lab (PMEL)

Who are we?

- **Predictive Maintenance for the Space Shuttle Program is based out of KSC and utilizes state-of-the-art technologies to monitor and trend equipment health.**

Bearing Failure Analysis

Thermography

Fluid Analysis

Ultrasonic Noise Detection

Motor Circuit Evaluation

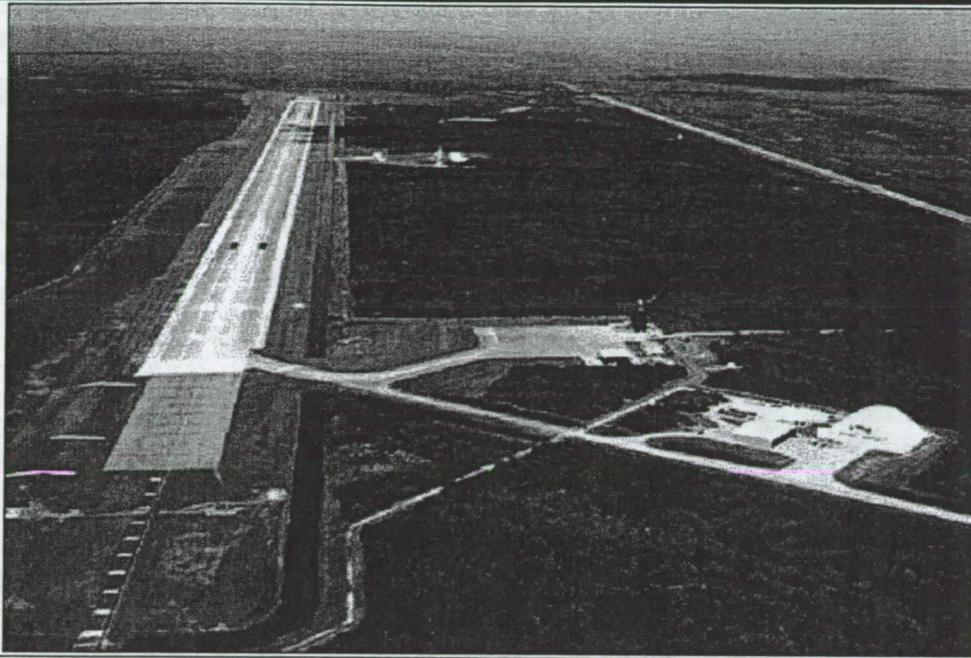
Vibration Analysis

- **Equipment condition trends are used to validate preventive maintenance cycles, reduce unplanned maintenance downtime, and improve machine reliability.**
- **PMEL Engineers perform acceptance and validation testing for new and rebuilt machinery thereby establishing the baseline for equipment health.**



The predictive maintenance engineering group. Formed in 1989 using Vibration analysis only, added Fluid and Thermography in 1992. MCA, laser alignment and ultrasonic noise detection followed soon after.

Shuttle Landing Facility (SLF)



KSC is overlaid with 140,000 acres of the Merritt Island National Wildlife Refuge.

Warn of the acronyms

Orbiter landings at the Kennedy Space Center are made on one of the largest runways in the world.

This aerial shot gives some idea of what approaching aircraft see as they reach the KSC shuttle runway. It's not quite this angle for a returning shuttle, which drops at a more severe incline and incredibly high speed on its way in. Kennedy Space Center.

The runway is 15,000 feet long and 300 feet wide with a 1,000-foot safety overrun at each end. In general terms, the runway is roughly twice as long and twice as wide as average commercial runways, although a number of domestic and foreign airports have landing strips far exceeding average dimensions.

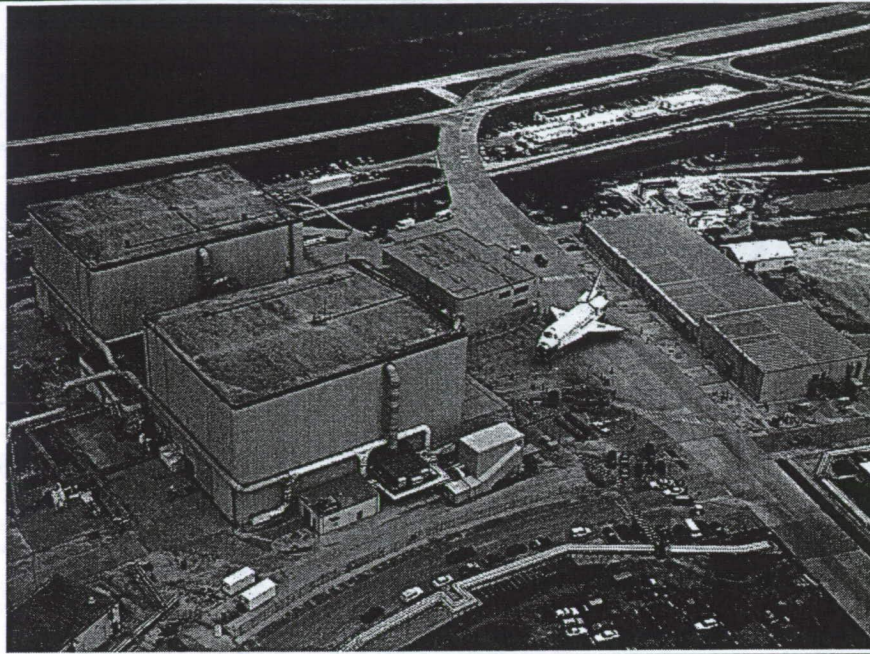
The Mate/Demate device (MDD) used to raise and lower the orbiter from its 747 carrier aircraft during ferry operations. The open-truss steel structure is equipped with hoists, adapters and movable platforms for access to certain orbiter components and equipment.

MDD Hoists that lift the Orbiter, MCA on Portable Purge Units (PPU), and Ground Coolant Units (GCU).

MCA data will be done on DC motors, now that we have the capability.

The landing facility is linked with the Orbiter Processing Facility by a 2-mile tow-way.

Orbiter Processing Facility (OPF)



After landing, the orbiter is towed to the Orbiter Processing Facility (OPF). The orbiter then undergoes safing procedures in the OPF which include removing residual hypergolics. Then the orbiter's previous mission payloads are removed and the vehicle is fully inspected, tested, and refurbished for its next mission.

Hyper Exhaust fans, All ECS equipment, Orbiter Hydraulics, Bridge Buckets, and HVAC equipment.

Image Credit: NASA

Vehicle Assembly Building (VAB)

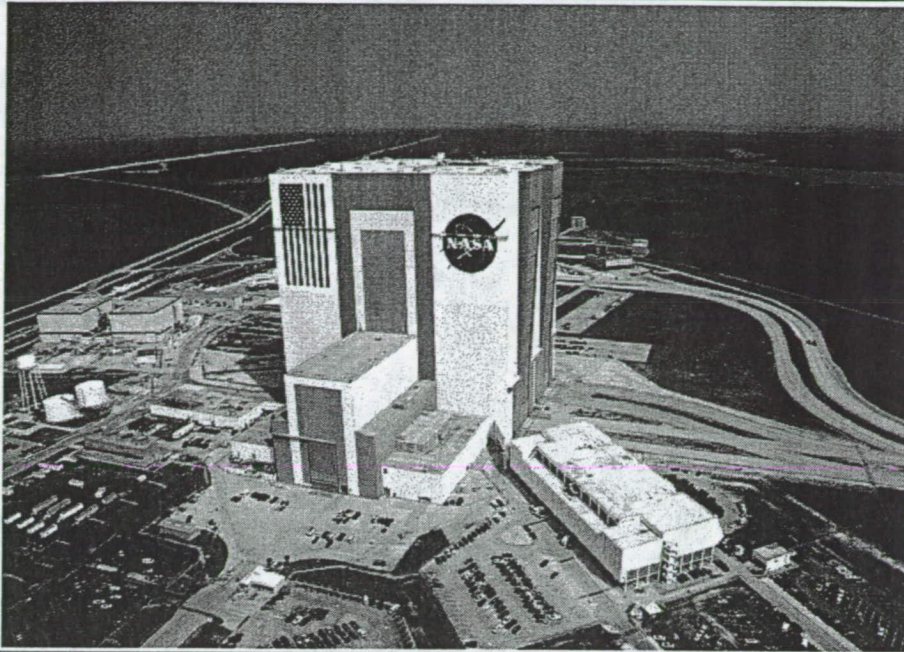


Image Credit: NASA

The Vehicle Assembly Building (VAB) is one of the largest buildings in the world. It was originally built for assembly of Apollo/Saturn vehicles and was later modified to support Space Shuttle operations.

Lifting Devices: 71 cranes; two 227 metric ton (250 ton) bridge cranes.

During Space shuttle build-up operations inside the VAB, integrated SRB (How Many segments?) segments are hoisted onto a Mobile Launcher Platform and mated together to form two complete SRBs. The ET, after arrival by barge, is inspected and checked out and then attached to the SRBs already in place. The orbiter is then towed over from the Orbiter Processing Facility to the VAB transfer aisle.

Going Vertical in the VAB

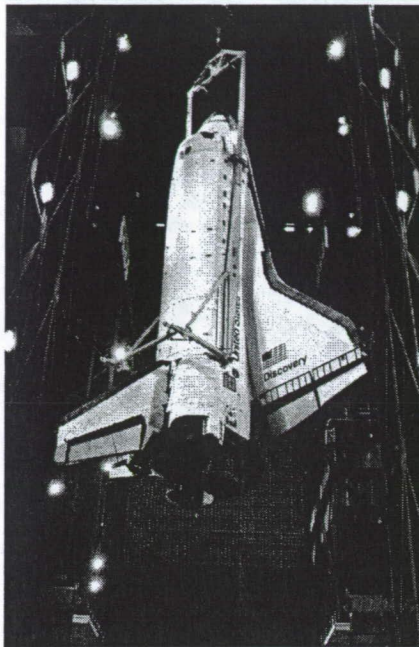


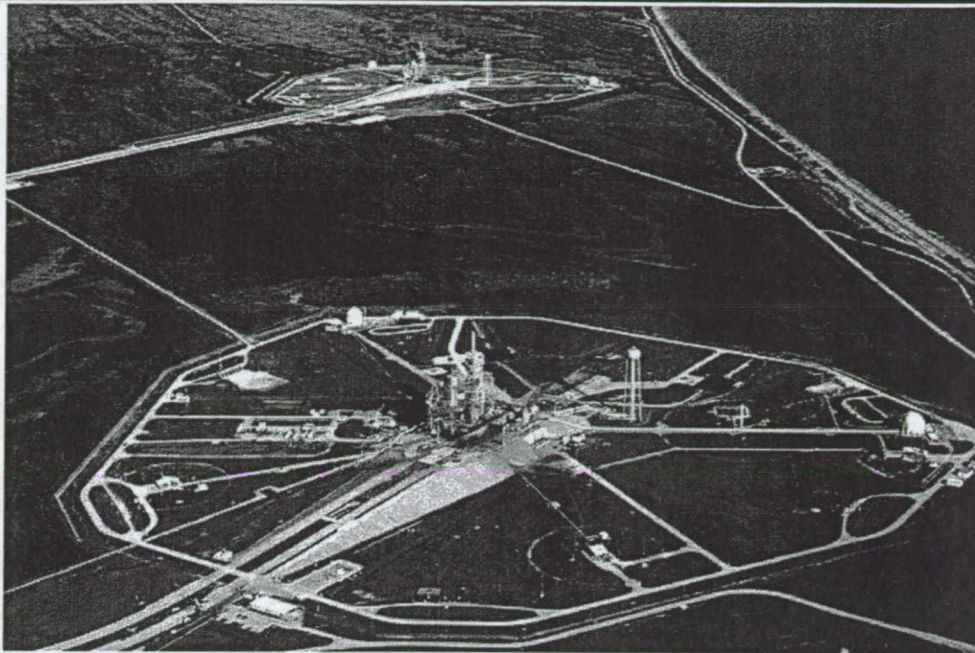
Image Credit: NASA

The Orbiter is raised over the 16th floor to a vertical position, lowered onto the Mobile Launcher Platform and then mated to the rest of the stack. When assembly and checkout is complete, the crawler-transporter enters the High Bay, picks up the platform and assembled shuttle vehicle and carries them to the launch pad.

List equipment PMEL tests in the VAB

HVAC equipment, Doors, Platform hoists, Mini PPU's. The large Cranes are DC drives and we will begin testing them now that we have the technology.

Launch Pads 39 A/B



Launch Complex 39's Pad A and Pad B were originally designed to support the Apollo program and were modified for Space Shuttle launch operations. Pads 39-A and 39-B are virtually identical and roughly octagonal in shape.

Propellant servicing of the Space Shuttle's reaction control systems, the booster auxiliary power units and the external tank is performed at the launch pad. Fuel lines lead from the propellant storage facilities to the pad structure and onward to the umbilical connections. These facilities include the hypergolic storage and distribution facilities.

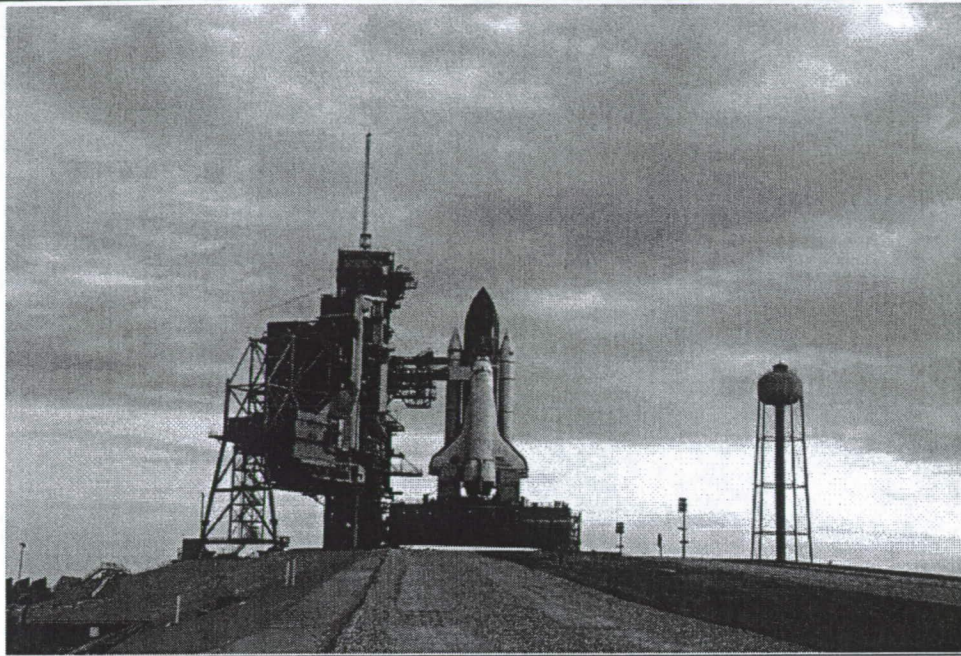
The orbiter's Orbital Maneuvering Subsystem (OMS) and Reaction Control System (RCS) engines use monomethyl hydrazine (MMH) as fuel and nitrogen tetroxide (N₂O₄) as the oxidizer. These toxic fluids can be stored at ambient temperatures. Being hypergolic they ignite on contact with each other. Therefore, they are stored in well-separated locations, at the southwest and southeast corners of the pads.

List Equipment PMEL tests at the Pads

All Environmental Control System (ECS) equipment, LOX Pump Motors (hardwired SKF vibration system), OMS Hypergolic Pumps, and Heating Ventilation Air Conditioning (HVAC).

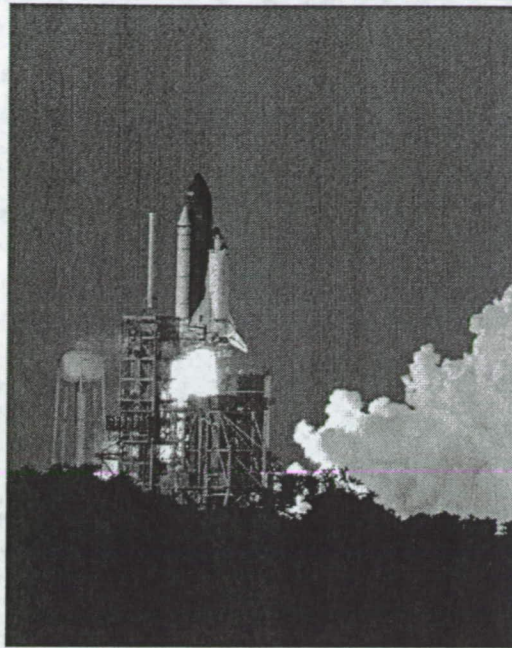
National Aeronautics and Space Administration
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899
FOR RELEASE: 03/01/2006
PHOTO NO: KSC-06PD-0390

STS-118



The Rotating Service Structure (RSS), moves around the shuttle for processing at the Pad and for protection. It also has a six story 100K class clean room, used for payload processing. The Fixed Service Structure (FSS) was originally used for the Apollo program, it was called the Launch Umbilical Tower (LUT)

STS-117 June 2007



Shuttle takes off ~4 million miles later it lands (Edwards or KSC) taken to OPF and processing starts again.

Mission: Space Station Assembly Building - 13A

Primary Payload: S3/S4 Truss

Space Shuttle: Atlantis

Launch Pad: 39A

Launched: June 8, 2007 - 7:38:04 p.m. EDT

Landed: June 22, 2007 - 3:49 p.m. EDT

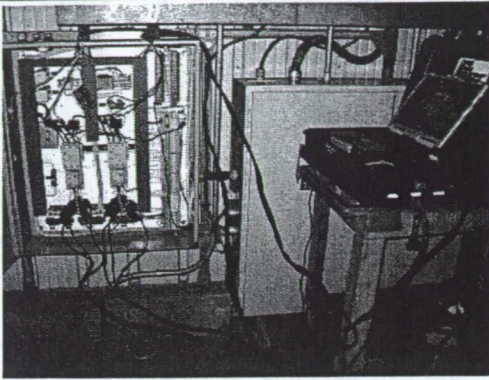
Mission Duration: 13 days, 20 hours, 12 minutes and 44 seconds

Inclination/Altitude: 51.6 degrees/122 nautical miles

STS-117: Building on Experience

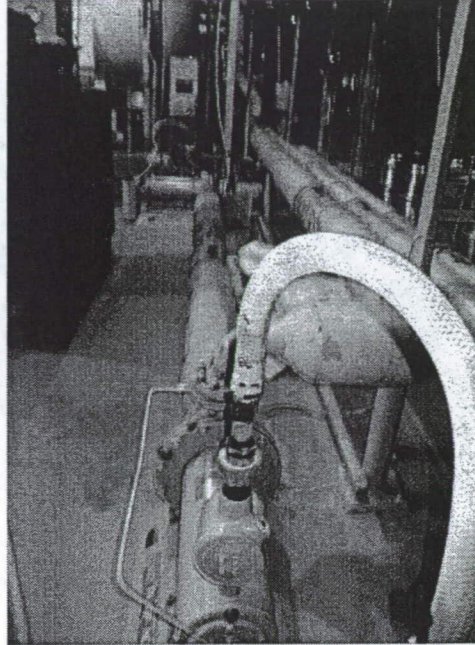
Space Shuttle Atlantis lifted off on mission STS-117 after a perfect countdown June 8, 2007, marking the first launch from Pad 39A at Kennedy Space Center in more than four years. During the 14-day mission, the astronauts conducted a total of four spacewalks to install and activate the S3/S4 truss segment, retract the P6 solar array and repair an out-of-position thermal blanket on the left orbital maneuvering system pod.

Test Set-up and Pad A pumps



Test set-up 7-22-2007 04:00

Pad A S00024 Operations STS-118



Not a typical set-up for these pumps, Baker loaned another tester so both pumps could be tested at the same time.

(Right picture) Pump #1 is at top center, discharge of this pump is rotated 90 deg so it's a straight shot to Pump#2.

Propellant Servicing



SCAPE operations for S00024; Pad is cleared, only personnel in SCAPE suits are allowed on Pad or at the Farms. Oxidizer is loaded then Fuel.

Here is a synopsis of the Hyper Load.

Pump #1 is turned on and pump #2 is turned on 30 seconds later. Output pressure DS of pump #2 runs between 315-330 psi.

- Flow is established up the tower and re-circulates back to the storage area.
- Once flow is detected at the skid inlets, flow is established in the skids and a leak checks of the skids are performed.
- Flow in the skids is maintained throughout the loading process.
- The FWD and AFT tanks are loaded in parallel.
- In the AFT, the OMS tanks are loaded first. Left OMS is loaded and then the Right OMS.(Fuel loads the right first then the left)
- Once OMS tanks are loaded the AFT RCS tanks are loaded. Left first then right. (Fuel loads the right first then the left)
- When both the FWD and AFT tanks are loaded and everyone is satisfied with the numbers, flow termination is initiated.
- Pumps are shut down and propellant freefalls back to the storage area.
- Blow downs are performed from the tower to the Storage

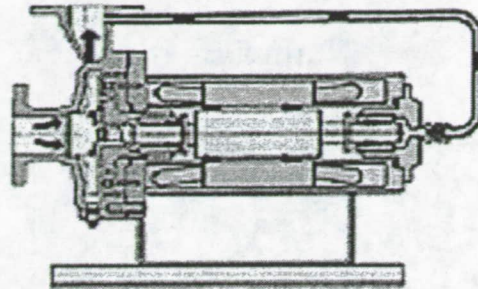
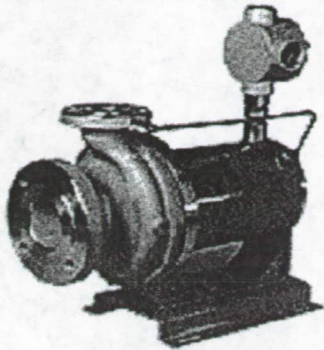
Pad Hyper Pump Testing

- PM cycle is very short, Oxidizer pumps must be inspected every 100-hours. Fuel pumps are on 300-Hour schedule.
- What are likely failure or historical failure modes
 - Journal bearing wear
 - Rotor stator contact and
 - Breaching jacket on stator
- PMEL began testing
 - Vibration test run in 1998 written into procedures in 2005.
 - Explorer first test run, August 2006.
- Operational Constraints
 - S.C.A.P.E. hazardous operations
 - All other processing at the Pad stops during S00024 operations.
- Test Setup Challenges
 - Monitor one pump at a time
 - timed loop acquisition



Two tester are required so both pumps can be tested at the same time. Since they have to capture data when no one is around, the Loop Acquisition function on the Explorer software is the only option available. They typically will take one run every 10 to 20 minutes. Propellant servicing requires three days of 24 hour operation, the Oxidizer pumps may operate for more than 7 hours at a time.

CRANE CHEMPUMP Series G



For normal clear fluid applications, Series G Chempumps are cooled and lubricated by the fluid being pumped, which flows through the circulating tube, into the rear of the rotor chamber, across the rear bearing, rotor, and front bearing, and then back into the main pumped stream through small holes provided in the rear of the impeller in the suction area.



Pump #1 discharge is rotated 90 deg so it's a straight shot to Pump#2.

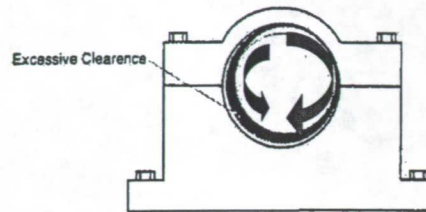
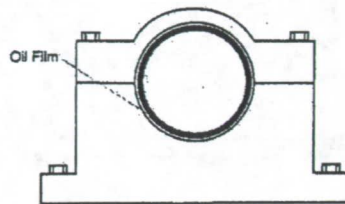
Rotor and stator are jacketed in Stainless steel. Primary failure mode concern; rotor stator contact and breaching jacket on stator which would result in an explosion and release of toxic propellants.

http://www.chempump.com/chempump_products/g_series/index.html

Information from Crane website.

Journal Bearings

Normal Bearing



Showing Excessive Clearance



These pictures can be used to illustrate how the oil whirl can exist in a journal bearing.

Left: shows normal bearing but it is somewhat deceptive because everything is symmetrical, usually this is not the case. Even in new bearings a high pressure wedge of oil forms depending on rotation where the oil is pressed between the shaft and bearing, a low pressure area forms on the opposite side of this. A bearing within tolerance will come to some position of equilibrium and usually stay there due to the pre-loading on the shaft.

Oil whirl typically shows up as a sub-synchronous vibration of the shaft speed (35% to 48% of RPM frequency)

The causes of oil whirl are usually poor bearing design, and bearing wear, but it can also be present on lightly loaded machines or a change in the fluid viscosity or machine alignment are other possibilities.

You will notice on the Pad Hyper pumps the load never dropped below 60%, so we can eliminate this possibility.

Possible Causes of Fluid Whirl

- **Poor bearing design**
 - Not an issue with these bearings
- **Lightly loaded machine**
 - Not an issue during normal operations
- **Change in fluid viscosity**
 - Not an issue during this operation, fluid is sampled before and after operation
- **Bearing wear**
 - Likely cause in these pumps



These pictures can be used to illustrate how the oil whirl can exist in a journal bearing.

Left: shows normal bearing but it is somewhat deceptive because everything is symmetrical, usually this is not the case. Even in new bearings a high pressure wedge of oil forms depending on rotation where the oil is pressed between the shaft and bearing, a low pressure area forms on the opposite side of this. A bearing within tolerance will come to some position of equilibrium and usually stay there due to the pre-loading on the shaft.

Oil whirl typically shows up as a sub-synchronous vibration of the shaft speed (35% to 48% of RPM frequency)

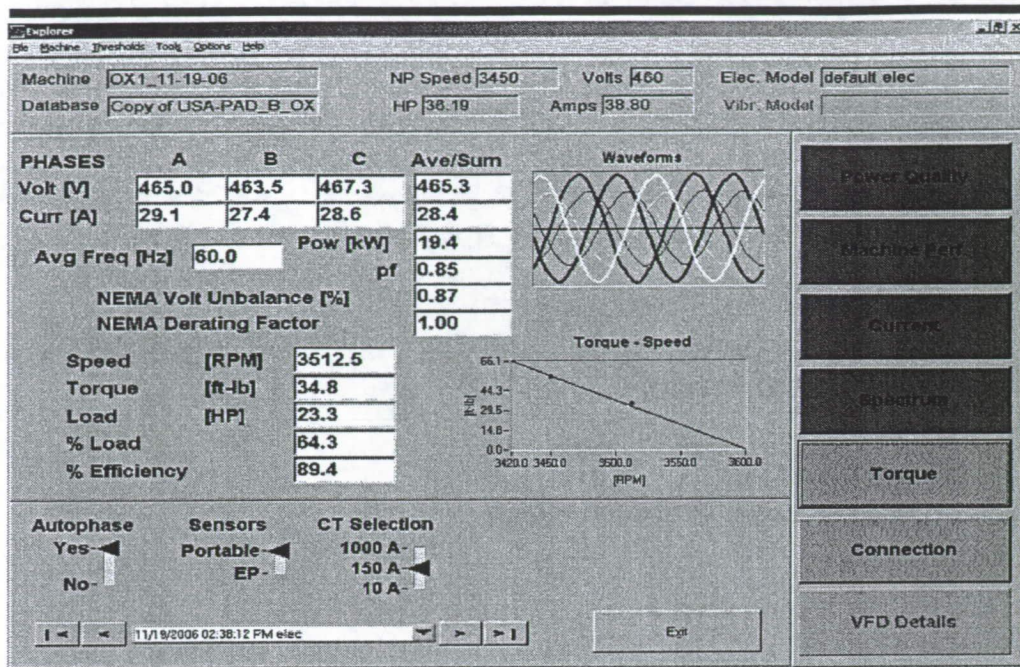
The causes of oil whirl are usually poor bearing design, and bearing wear, but it can also be present on lightly loaded machines or a change in the fluid viscosity or machine alignment are other possibilities.

You will notice on the Pad Hyper pumps the load never dropped below 60%, so we can eliminate this possibility.

Pad B Ox #1

11-19-06

02:38:12 PM



The first test we will show was taken on Pad B Oxidizer #2 in November of 2006.

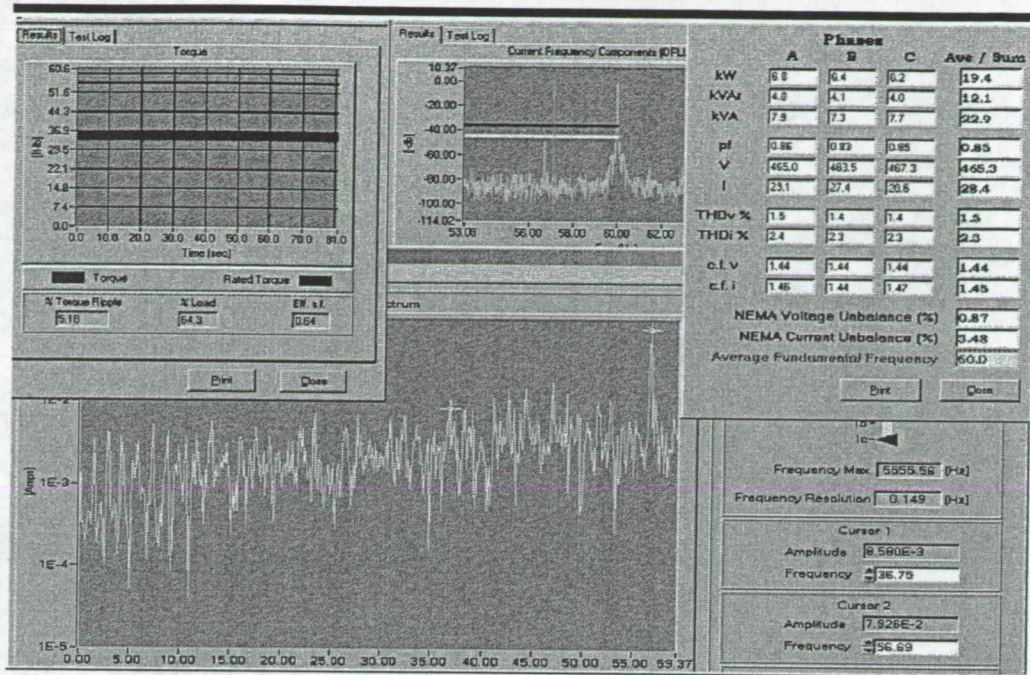
Propellant servicing requires three days of around the clock operation, the Oxidizer pumps may operate for more than 7 hours at a time, this last time Oxidizer load took more the two days.

This is just one of 23 runs captured on Pump #1 in November of 2006. No problems noted on the front panel, except the speed is off but that is not apparent right now.

Pad B Ox #1

11-19-06

02:38:12 PM



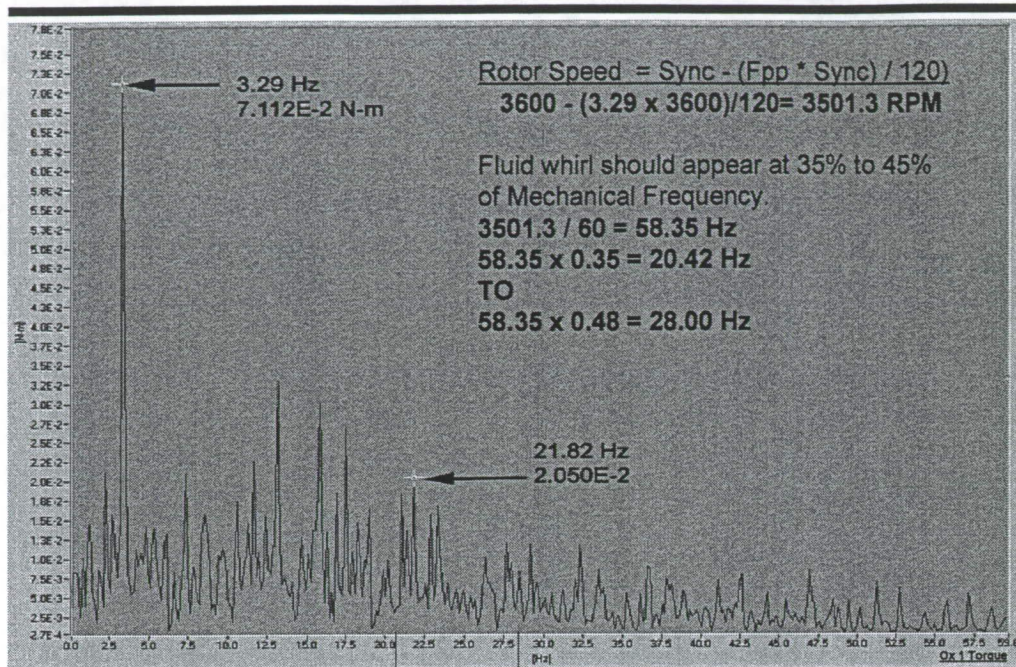
SC4

Torque ripple looks ok at ~5%, rotor bar sidebands appear to be ok. Note speed capture is incorrect, this may be due to the very high slip of these motors. Current spectrum (0-60 Hz) looks good, and all other electrical data looks nominal.

Pad B Ox #1

11-19-06

02:38:12 PM



Linear plot of Torque spectrum taken at the same time. The peak at 3.29 Hz is the Fpp (Frequency Pole Pass). Rotor speed can be calculated from this peak very accurately using the following formula ...

$\text{Sync} - (\text{Fpp} * \text{Sync}) / 120$ so $3600 - (3.29 * 3600)/120 = 3501.3 \text{ RPM}$.

Since the primary failure mode of these pumps are rotor stator contact by excessive bearing clearance.

Fluid whirl should appear as a sub-synchronous peak of the mechanical frequency.

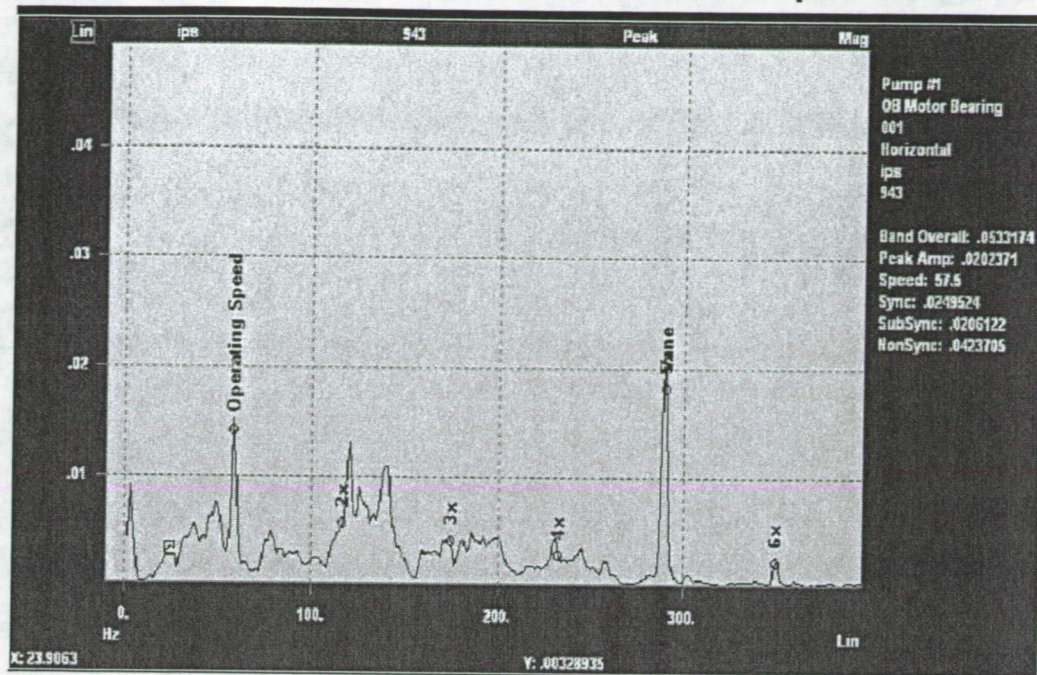
Mechanical frequency calculated by $\text{RPM}/60$ or $3501.3/60 = 58.35 \text{ Hz}$ (may or may not show in torque spectrum indication of imbalance).

Oil Whirl calculated at 35% to 48% of Mechanical Frequency

Where $0.35 * 58.35 = 20.42 \text{ Hz}$ to $0.48 * 58.35 = 28.00 \text{ Hz}$

Based on the calculations and the spectrum, there are no indications of fluid whirl.

Vibration Spectrum



USA
United Space Alliance

Summary of Ox #1 analysis

- **Explorer and Vibration analysis data are in agreement**
- **Pump healthy no fluid whirl**
- **Recommendation continue normal operations until 100 hour planned maintenance cycle**



So to review on Pad B Oxidizer #1 the Explorer results were validated by vibration analysis.

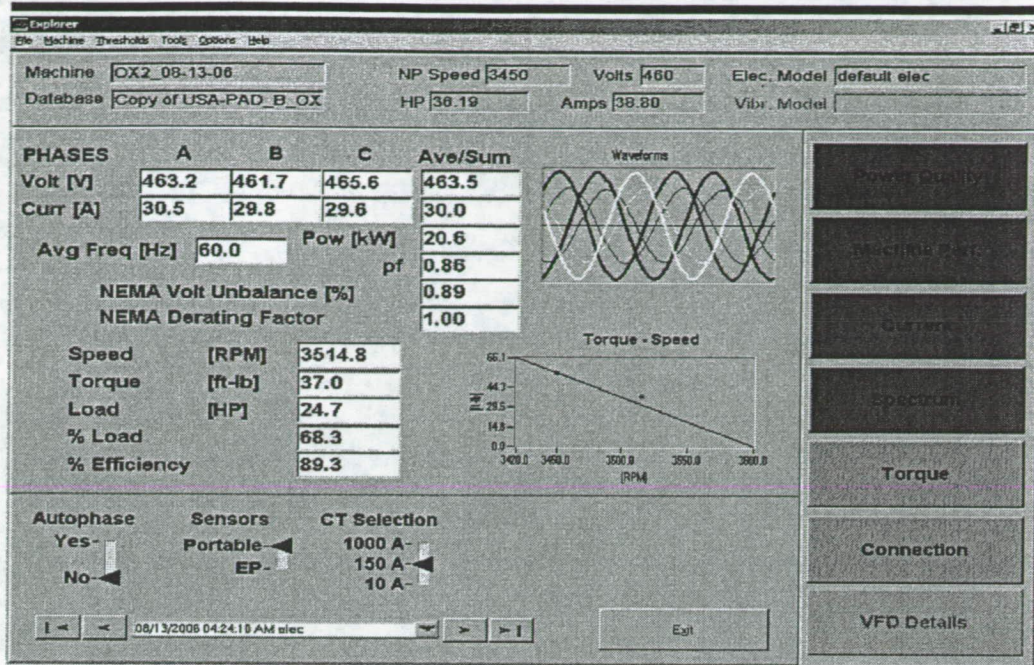
The pump was determined to be healthy and we recommended to continue normal operations.

Unfortunately there is still has a 100 Hour disassembly rule for these pumps.

Pad B Ox #2

8-13-06

03:50:14 AM



SC7

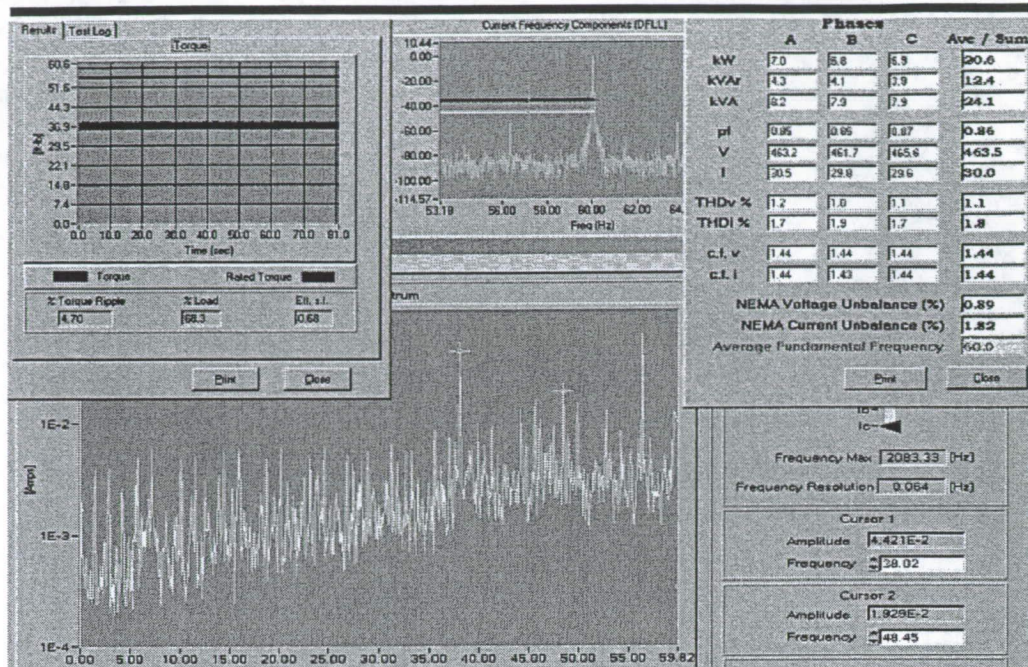
This is one of 34 runs captured in Aug 2006 on Pump #2. Again there are no apparent anomalies.

Voltage looks good, balanced current, good power factor, speed is believable (for now), % load is good, everything looks great.

Pad B Ox #2

8-13-06

03:50:14 AM



USA
 United Space Alliance

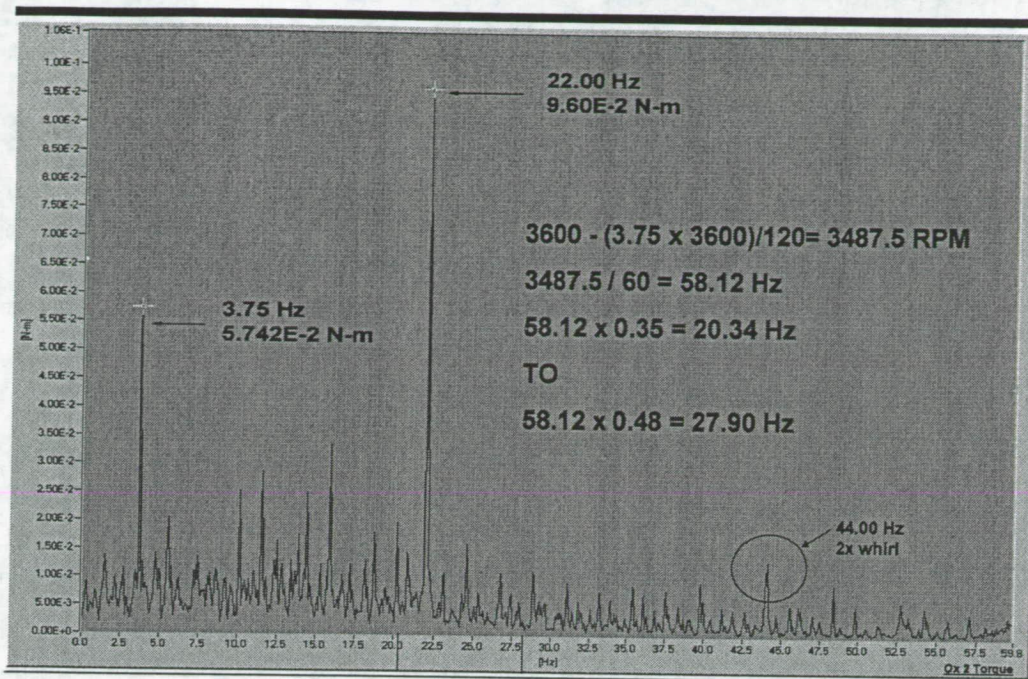
SC8

Torque ripple is good at <5% actually a little lower than Pump #1, rotor side bands greater than 45 dB down also shows in current spectrum at 56.27 Hz (missed the speed again). There does appear to be an unknown peak in the current spectrum at approximately 38.02 Hz, all other electrical data is nominal.

Pad B Ox #2

8-13-06

03:50:14 AM



SC9

Linear plot of Torque spectrum. Fpp at 3.75 Hz = 3487.5 RPM (Note Pump 1 Fpp level was ~.07 N-m).

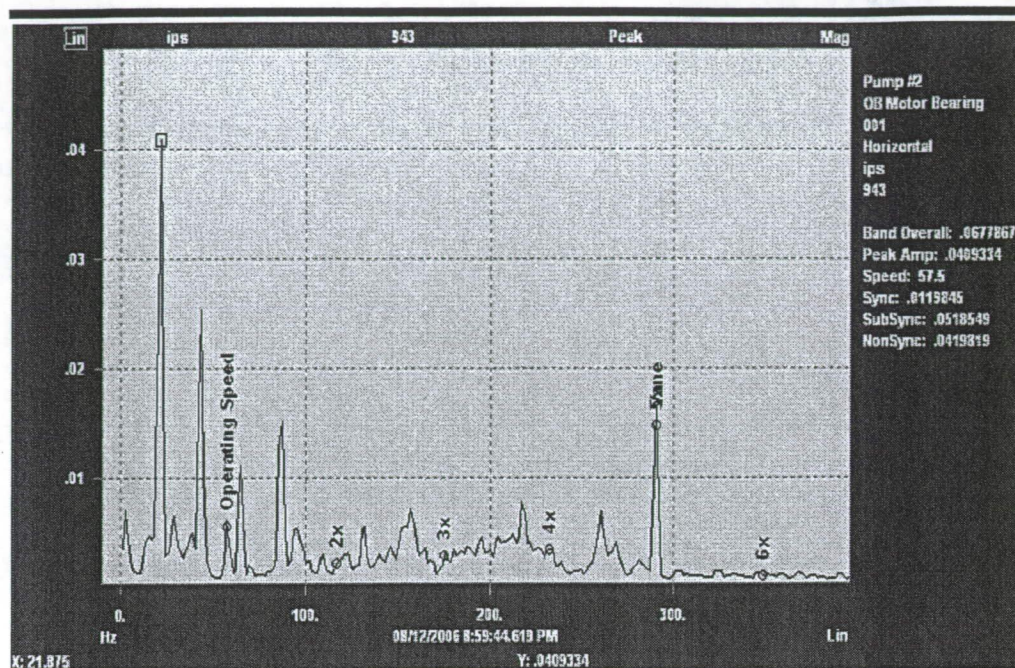
Mechanical frequency $3487.5/60 = 58.12$ Hz

Obvious peak at 22.00 Hz ($22.00/58.12 = 0.378$) or 38%. This is indicative of fluid whirl.

Interestingly enough, there is also a peak at approx. 44 Hz. It may be an fluid whirl severity indicator which would be useful in determining remaining useful life.

Side note: $60 - 22.00 = 38$ Remember 38.02 Hz peak in current spectrum? Strange that it appears in all Ox2 data but not in Ox1.

Vibration Spectrum



USA
United Space Alliance

Vibration was taken the night before and also shows fluid whirl @ 21.87 Hz.

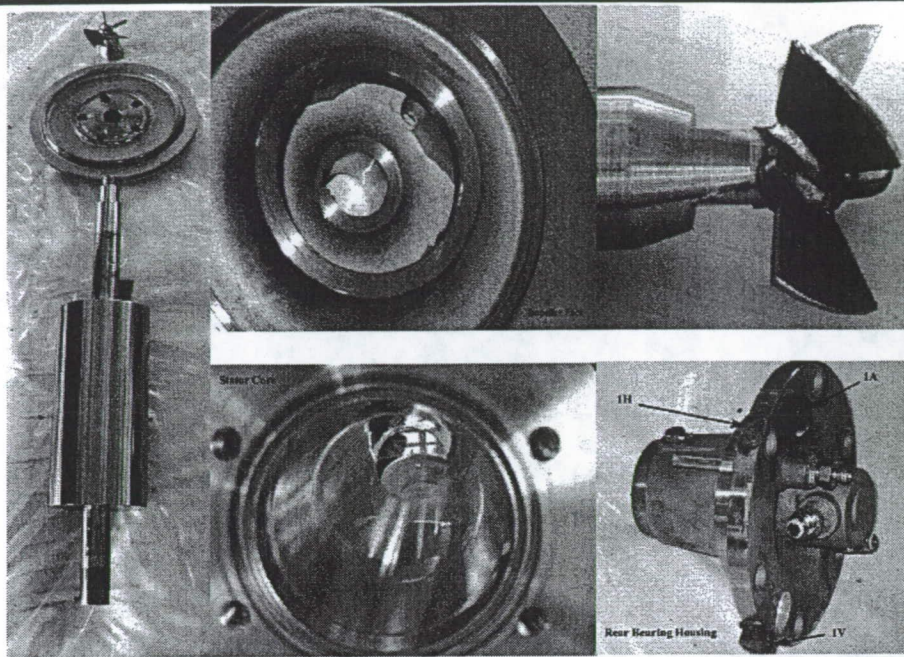
Summary of Ox #2 MCA analysis

- **Vibration data indicated fluid whirl**
- **Explorer torque spectrum indicates possible fluid whirl**
 - **Possible severity indicator peak at 2x fluid whirl**
- **Unknown peak at 38Hz in current spectrum may be an alternative method of detecting whirl. ($60 - 38 = 22$)**
- **Eccentricity peaks at mechanical frequency times number of rotor bars is possible**
 - **Fmax was set to low to capture eccentricity peaks during this operation**



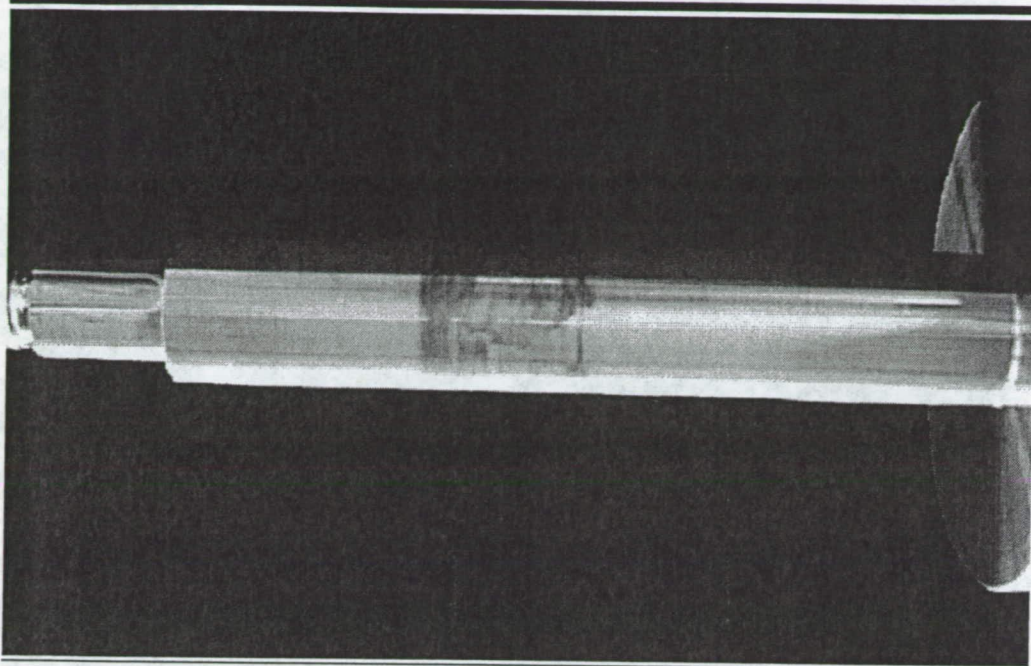
Since this was essentially the first time fluid whirl was seen with the explorer validation was needed. This included testing at Pad A and inspection of Pad B pump #2.

Pad B Ox #2 pump assembly



Pad B Ox#2 pump disassembled in March 2007. Clockwise from Left side; Rotor-impeller- and flow inducer, suction side of impeller, flow inducer, rear bearing housing, and the stator core.

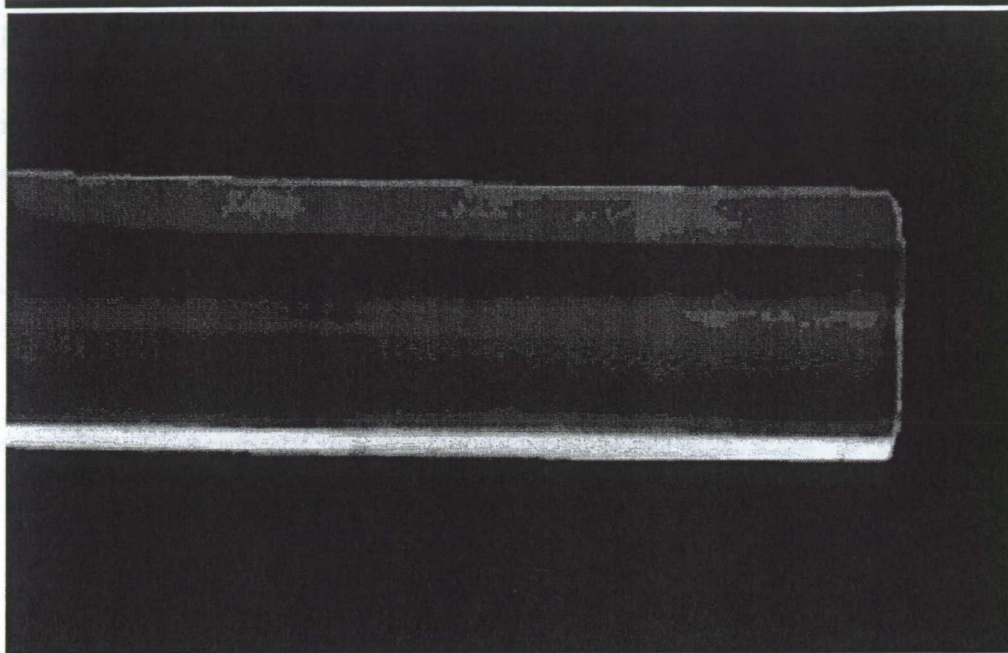
Front Journal Ox #1



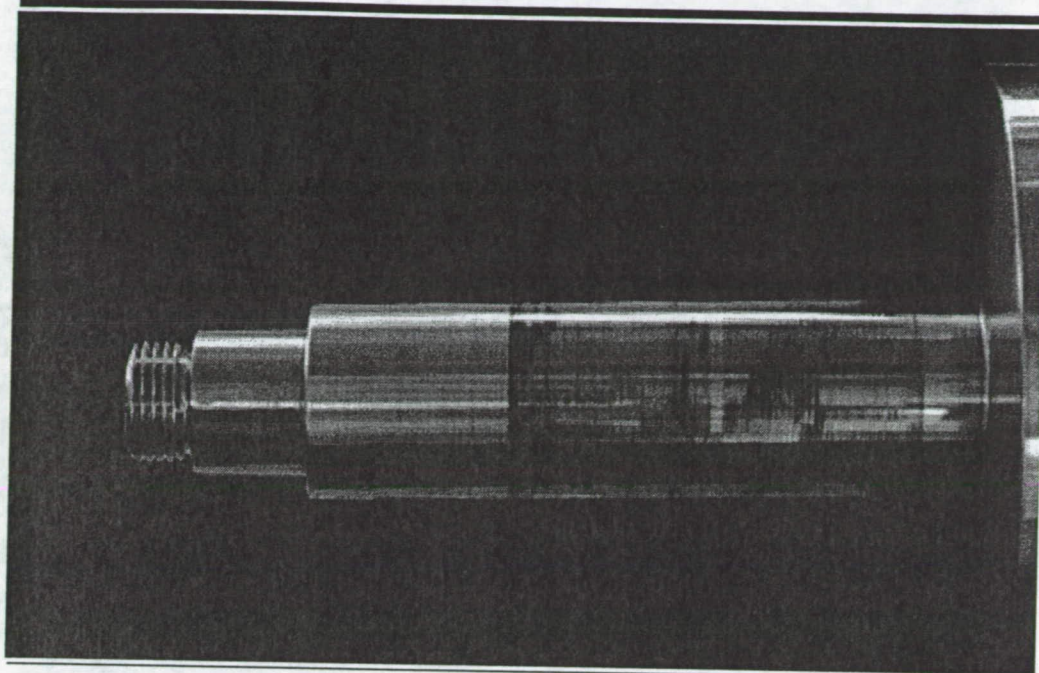
USA
United Space Alliance

Pad B Ox #1 front journal

Rear Journal Ox #1



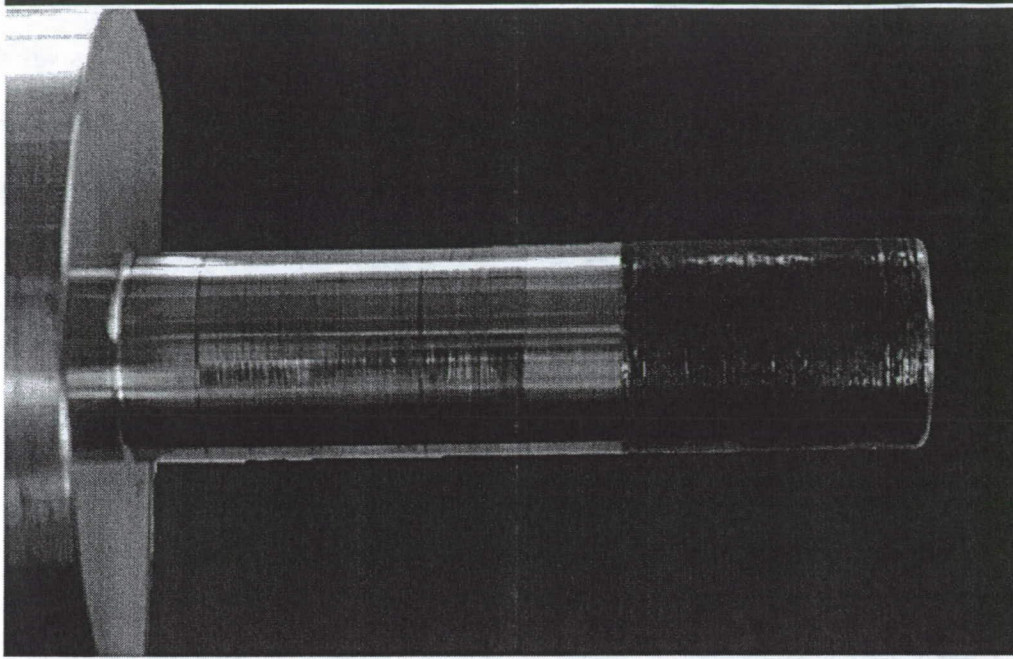
Front Journal Ox2



USA
United Space Alliance

Pad B Ox #2 Front journal.

Rear Journal Ox2



Pad B Ox #2 Rear journal.

Bearing and Journal Dimensions (Ox 1 and Ox2)

Manufactures Specifications		Ox Pump #1		Ox Pump #2	
		Front	Rear	Front	Rear
Journal	1.1833" - 1.1840"	1.183"	1.184"	1.184"	1.184"
Bearing	1.1880" - 1.1890"	1.189"	1.191"	1.193"	
Clear	.0048" - .0057"	0.006"	0.007"	0.009"	
<i>Note: Manufactures maximum diametrical clearance is 0.014"</i>					

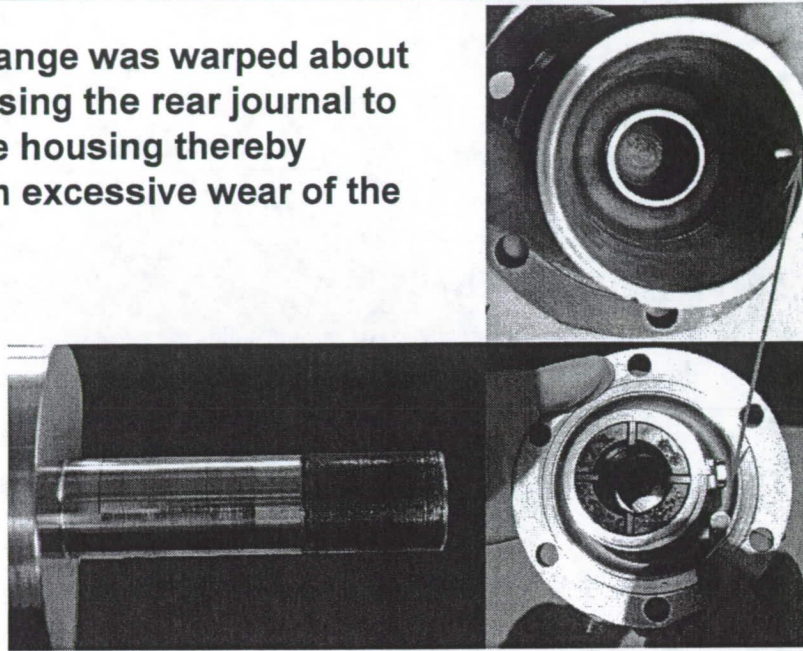


Looking at the table Oxidizer #1 front and rear journal and the front bearing are within new specifications. The rear bearing is slightly out of spec., but both could have been used and a considerable amount of life has been wasted.

The same is true of the Front bearing on Oxidizer #2 but the rear bearing has considerable wear and is significantly out of tolerance. The 0.010" over MAX tolerance is believed to be why oil whirl was observed on Ox pump #2.

Root Cause of Pad B Ox Pump #2 Failure

Housing flange was warped about 0.020" causing the rear journal to contact the housing thereby resulting in excessive wear of the bearing.



USA
United Space Alliance

The root cause of the rotor rub was suspected to be the rear bearing housing flange. It was found to be warped ~0.020".

Summary Ox 1 and 2

•Pad B Ox 2 was disassembled first and showed significant wear on the rear bearing and also had significant rotor rub

•If condition based maintenance were used it would have been possible to salvage the rotor and bearing, if the pump was removed from service earlier

•Pad B Ox 1 disassembly showed no abnormal wear

•With condition monitoring this pump could have remained in service and not been disassembled

•This pump had considerable remaining useful life (RUL) which was wasted when it was disassembled

•Re-assembly may introduce new problems into this pump

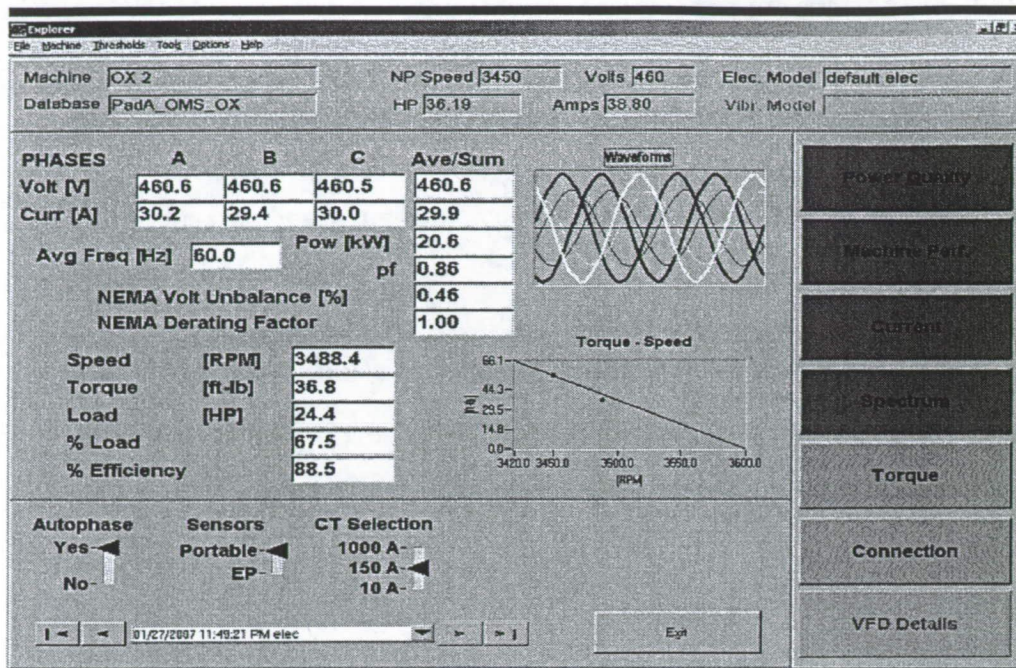


•(NOTE first bullet: CBM was not being consistently being performed when pump first started)

Pad A Ox #2

01-27-07

5:32:26 PM



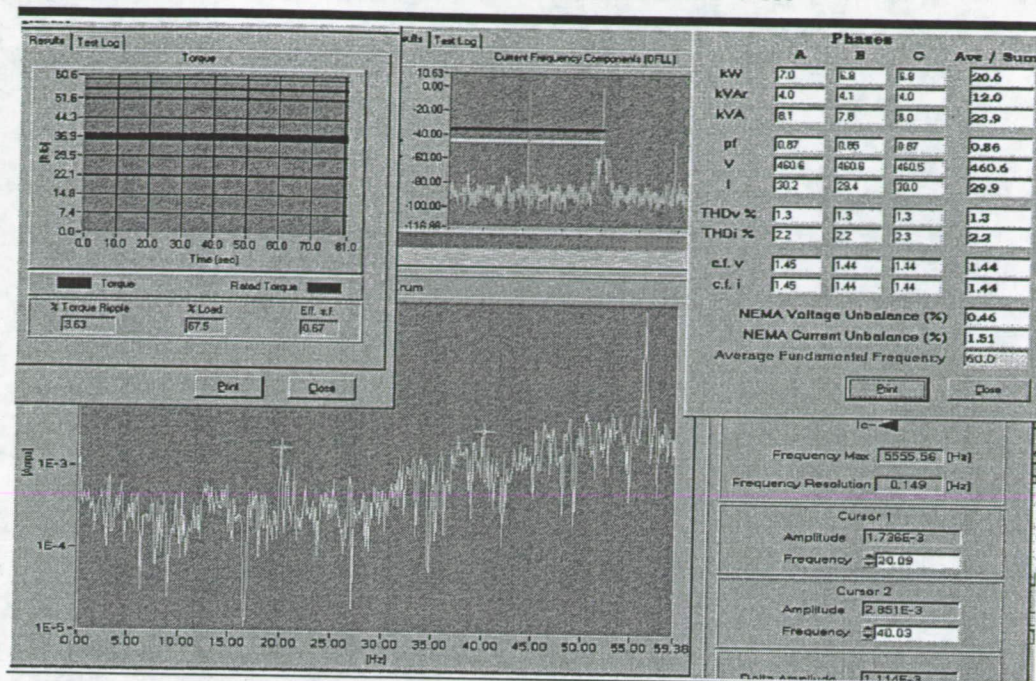
SC11

This is one of 17 runs captured in January 2007 at Pad A Pump #2. Again no apparent anomalies.

Pad A Ox #2

01-27-07

5:32:26 PM



USA
United Space Alliance

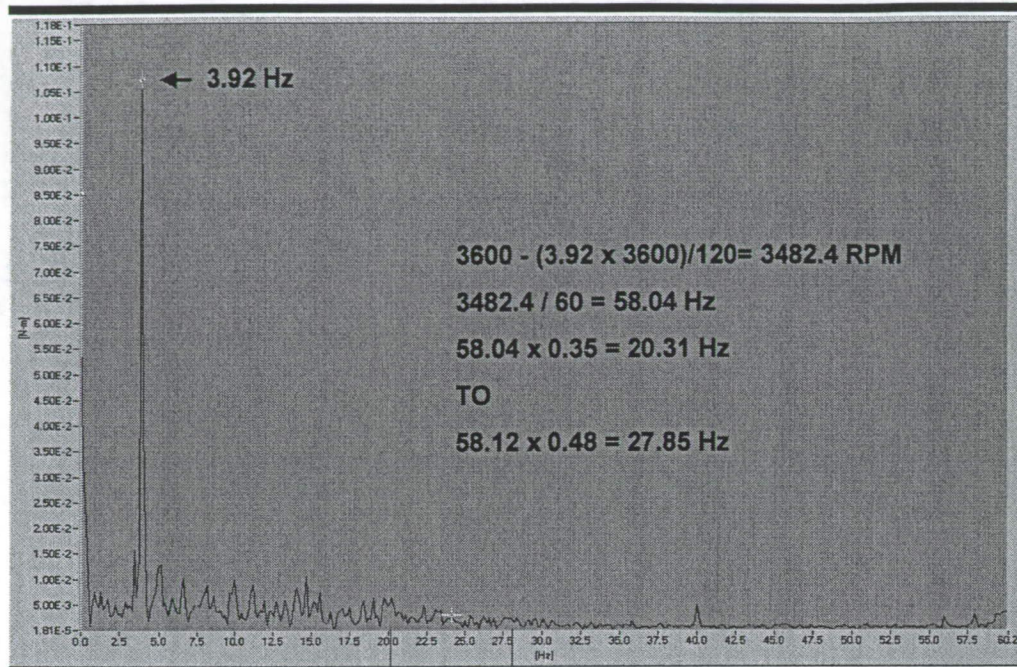
SC12

Torque ripple is good at <4%, rotor side bands greater than 45 dB down also shows in current spectrum at 56.16 Hz (speed captured correctly!!!). all other electrical data is nominal.

Pad A Ox #2

01-27-07

5:32:26 PM



USA
United Space Alliance

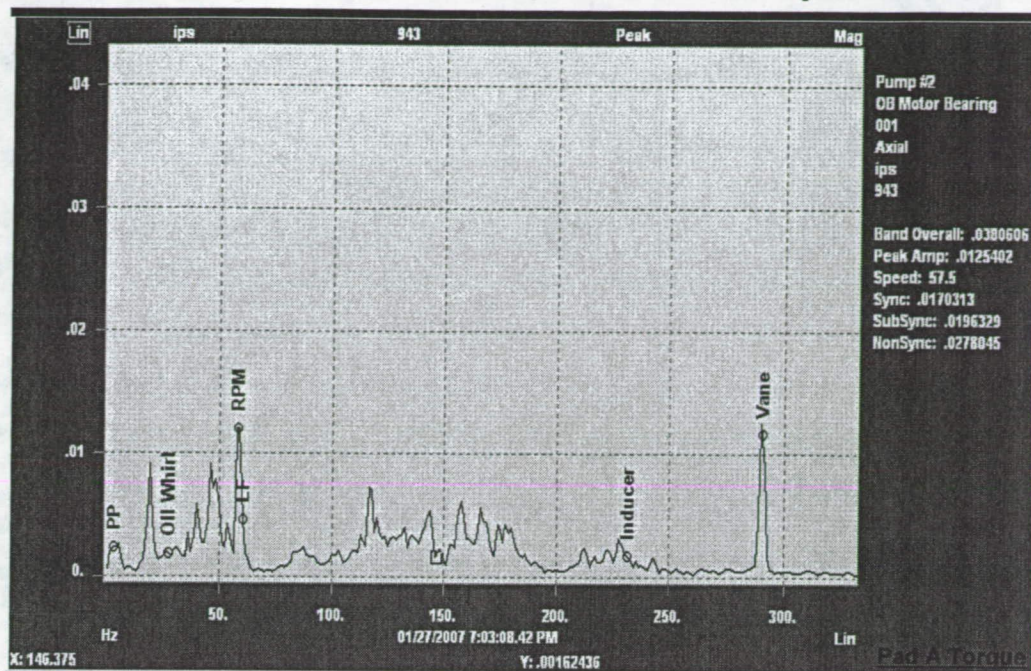
SC13

Torque spectrum looks nominal. No abnormal peaks.

Pad A Ox #2

01-27-07

Vibration Spectrum



SC13

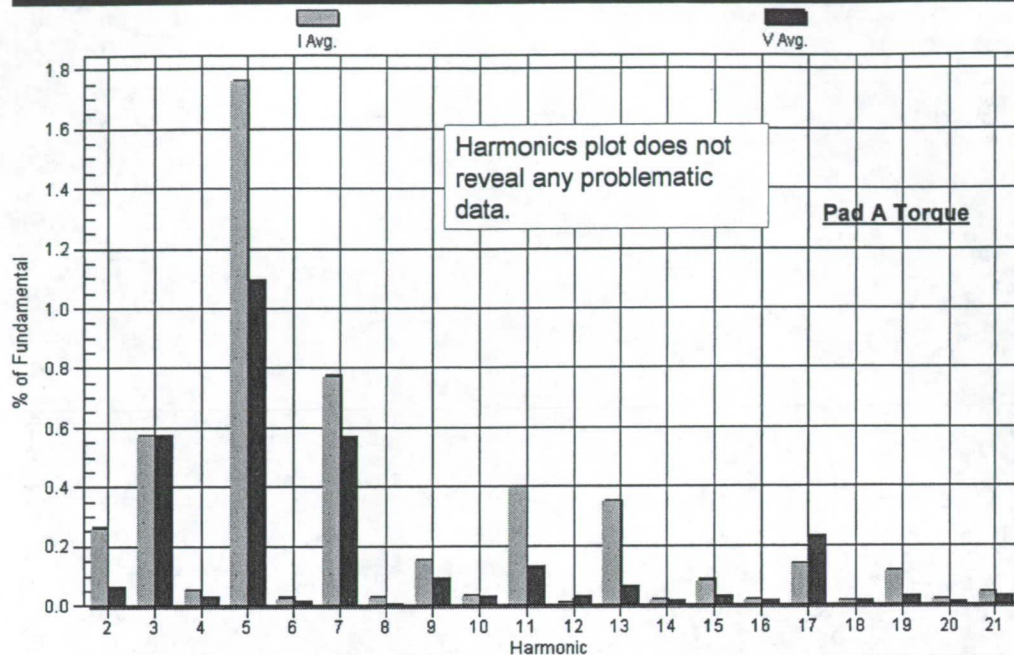
Vibration analysis reported fluid whirl in their report. This was not corroborated with the Explorer, which indicated the sub harmonic peak was a voltage distribution problem, there are SCR heaters on the bus which feeds these motors and the heaters were operating during this period.

Advanced data analysis may be required to determine if erroneous vibration data exists. By exporting the raw data (torque, voltage, and current), and plotting it was determined to be a voltage issue not fluid whirl.

Pad A Ox #2

01-27-07

Harmonics Run 5



Harmonic data does not reveal problems with voltage, because there were sub-harmonics on the line not harmonics the Crest Factor for Current does increase when these sub harmonics appear but not the Crest Factor for Voltage.

Preventative Maintenance (PM)

- **Preventative Maintenance:** time-based tasks including inspection, service and/or replacement.
 - Established cycle based on average statistical data, anticipated lifetime, or manageable impact from temporary loss of asset.
- PM may be invasive, requiring an outage and disassembly for visual inspection and/or overhaul/replacement regardless of condition.
 - The intervals between specific Preventive Maintenance tasks are based on average life or risk assessment.
- A PM program can be cost effective when equipment operation is consistent, average life is predictable within a reasonable span, failures are well understood and manageable, and useful failure statistics are available.



In review,

PM can be an effective maintenance practice IF a there is a sufficient population to base failure data on.

Predictive (PdM) or Condition Based Maintenance (CBM)

- **PdM/CBM: Maintenance action based on actual condition obtained from in-situ, non-invasive tests, operating and condition measurements.**
 - **Condition Based Maintenance has proven capable of identifying faults early enough to minimize the impact of:**
 - operational interruptions
 - avoid expensive failures
 - including collateral damage
 - significantly reduce the cost of maintenance.
- **Some potential failures, such as fatigue, are not easily detected with condition measurements.**



CBM makes decisions on actual condition not statistical data.

Criteria for Applying CBM

Preliminary Questions:

Does the technology monitor a specific failure mode?

Is it probable that this failure mode will occur during the lifetime of the equipment?

Application Criteria:

Changes in specific equipment parameters must correlate to corresponding failure mode.

The parameter must be accurately and consistently measurable.

There must be enough time between potential and functional failure to allow for corrective action.

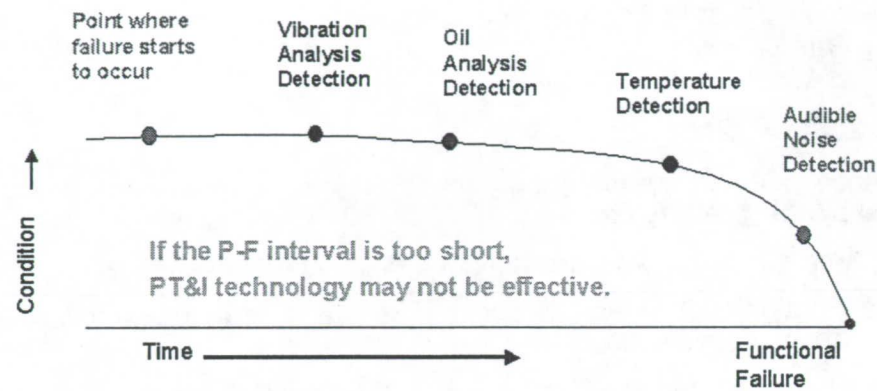
The monitoring interval must be shorter than the P-F interval.

Multiple monitoring points during the P-F interval increases confidence in the diagnosis.



- 1, Yes, vibration analysis and MCA can both identify the primary failure mode on these pumps
2. It has happened before, (1998).

P-F curve

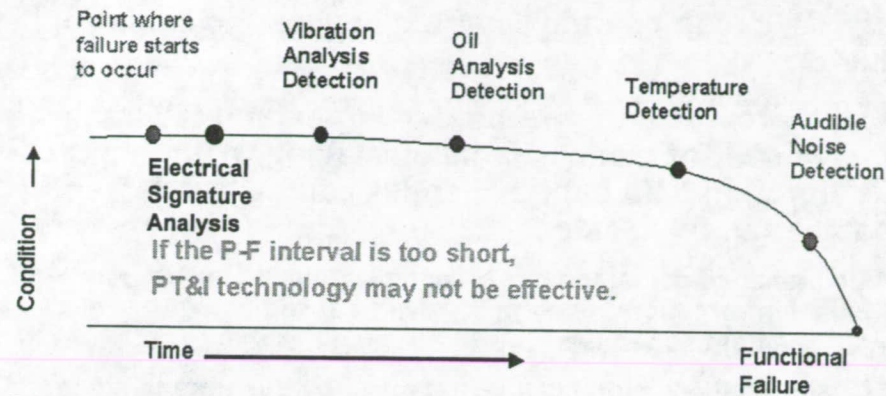


Reliability-centred Maintenance, by John Moubray



The P-F curve is used to illustrate where a failure starts to occur in the life of a piece of equipment and where each technology could possibly detect that failure. I don't like this curve too much because there is no one best analysis technique and it obvious, John Moubray came up with this before MCA was available... I doubt that but he may not have been aware of it's power.

P-F curve (modified)



Reliability-centred Maintenance, by John Moubray



Now this looks better. But if you think about ESA has actually found a fault before it has started to degrade the system, remember the Pad A Heaters? If this problem is not addressed then problems could escalate.

But now the problem is trying to determine which technology, and at what frequency you should monitor every piece of equipment,

If the time between the failure starting point and the functional failure is small then you just aren't going to be able to catch the failure (typical of fatigue fractures).

But if we continue to monitor the Pad Hyper pumps every time they operate then we should not miss a failure, unless the start of the failure to complete failure is very fast.

Now journal bearings historically do not wear out very fast and there should be plenty of time to predict a problem with this failure mode.

On-Line Monitoring

- **Objective:** Improve on-line monitoring of Oxidizer and Fuel motors during S00024 operations
- **Need:** Because bearing wear out can lead to catastrophic failure.
- **Impact:** provide early warning of impending failures which can be used for tactical decision making. With Explorer and Vibration data subtle changes can be trended and disaster can be avoided.
 - Maintenance decisions can be optimized by including condition based information to determine overhaul and planned replacement schedules.
 - Operational decisions can be improved by understanding and relating machinery condition to operational load and predicted time to failure.
 - The value of these On Line Monitoring techniques will be increased availability and reduced maintenance costs.



One objective of this presentation is to convince the decision makers that a CBM approach can detect the primary failure mode of these pumps and this could extend the lifetime and reduce total life-cycle costs considerably on these pumps.

Fault Detection

- **Issues: What fault modes are detectable with currently installed instrumentation?**
 - Voltage/Current balance
 - Loss of power
- **What can be detected with Vibration Analysis and Explorer?**
 - Rotor rub
 - Whirl (a.k.a. Oil Whirl)
 - Impeller issues
 - Resonance issues
 - Rotor faults (Porosity, broken bars, etc...)
 - Eccentricity (Static and Dynamic)
 - Electrical Faults and other hidden problems (power quality)



1 Voltage and current are now monitored but this is sampled only a few times per second. One failure mode this may be able to detect would be shorted turns on one phase if current imbalance became noticeable.

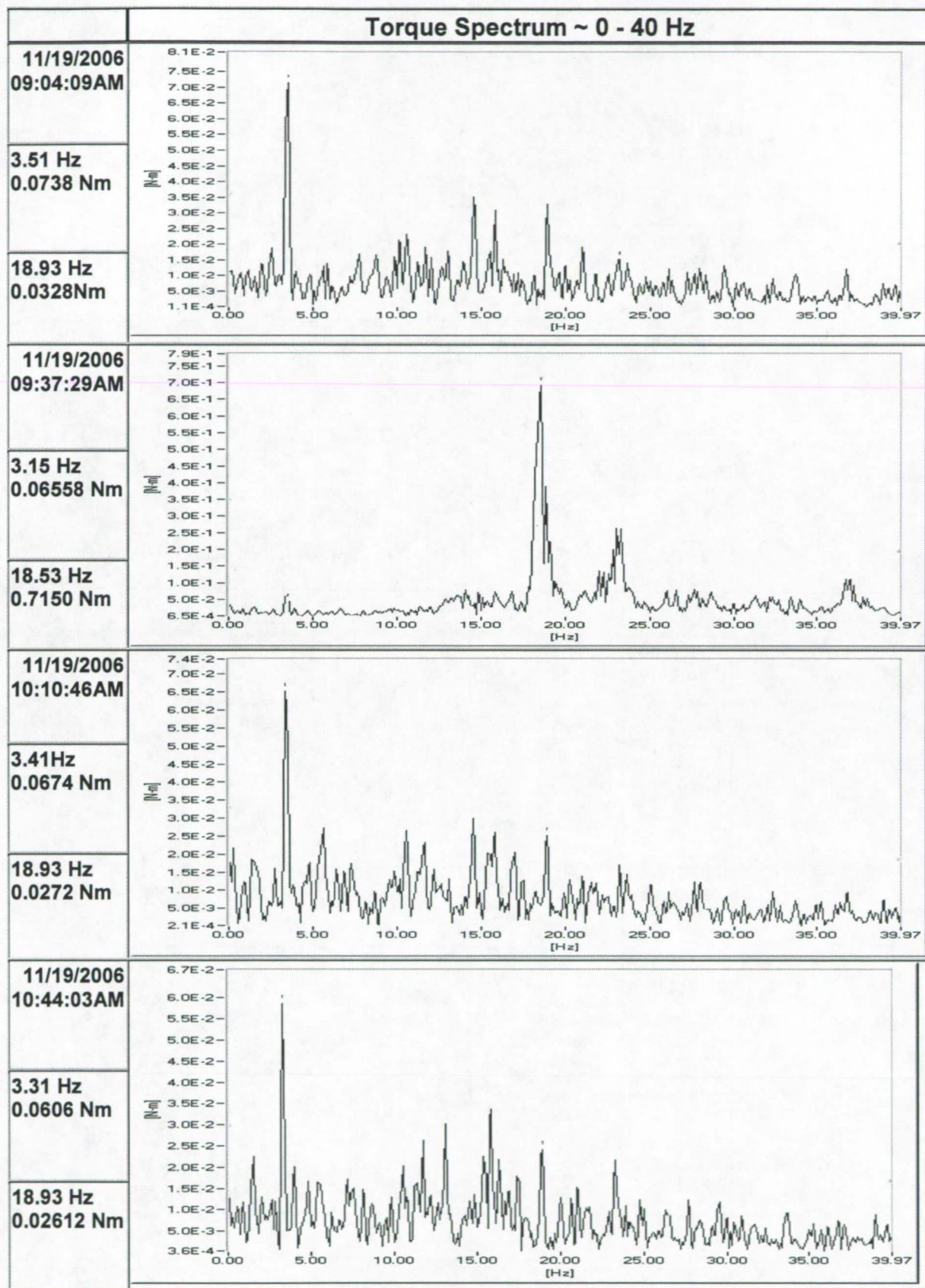
2 Combining Vibration and MCA would be able to detect the most serious failure modes rotor rub.

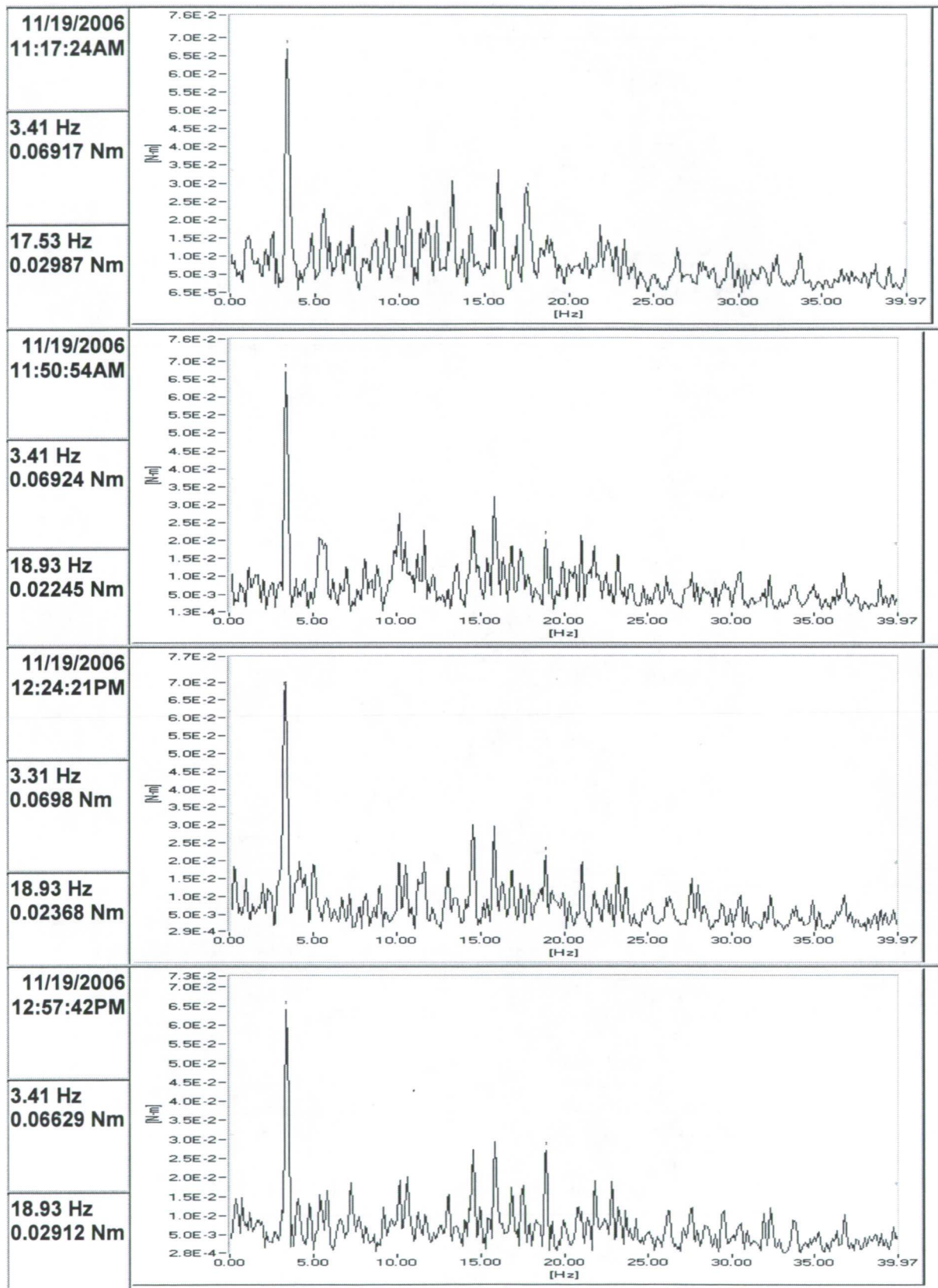
Electrical Faults and other hidden problems Pad A heater operations.

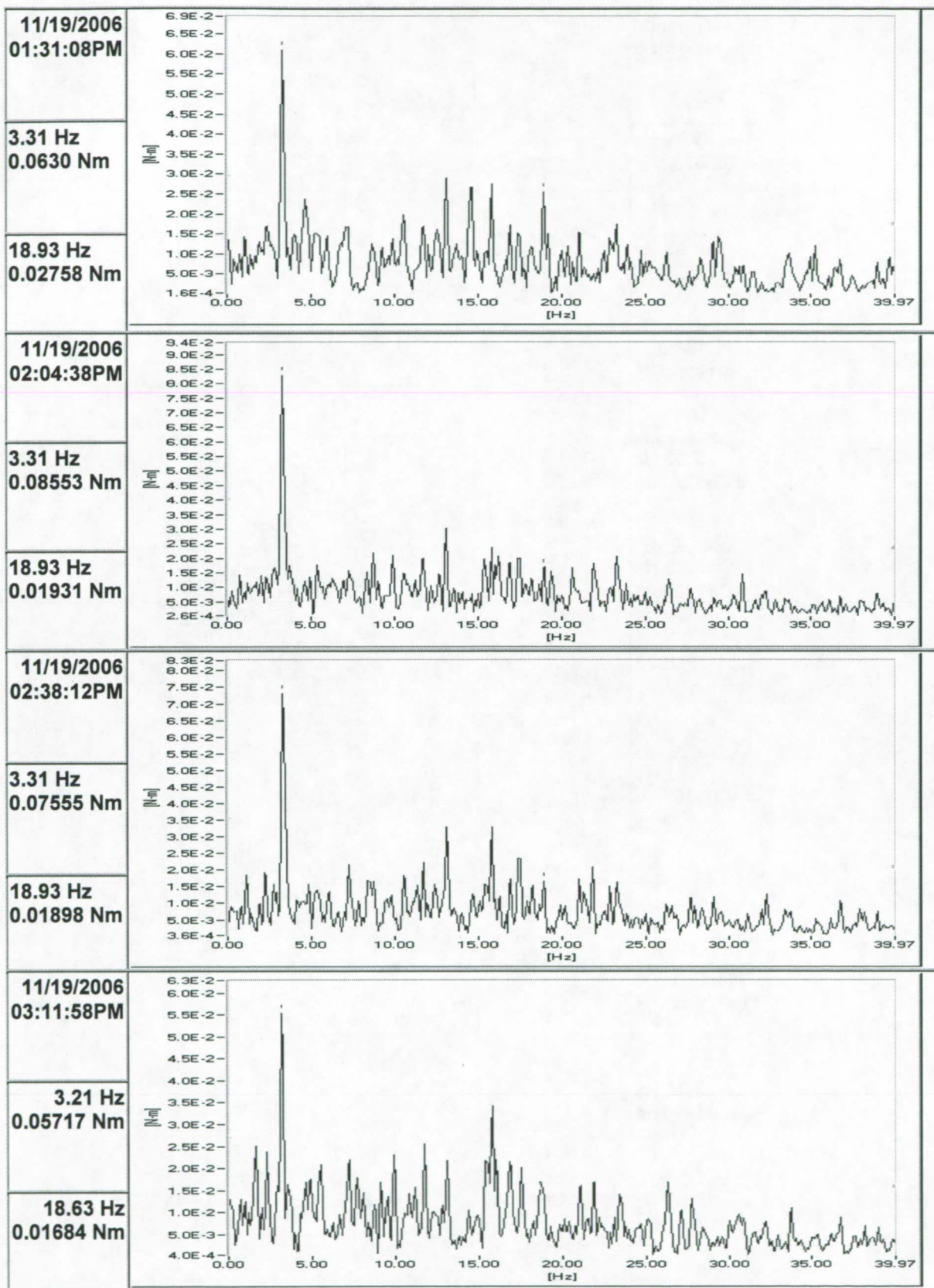
Summary

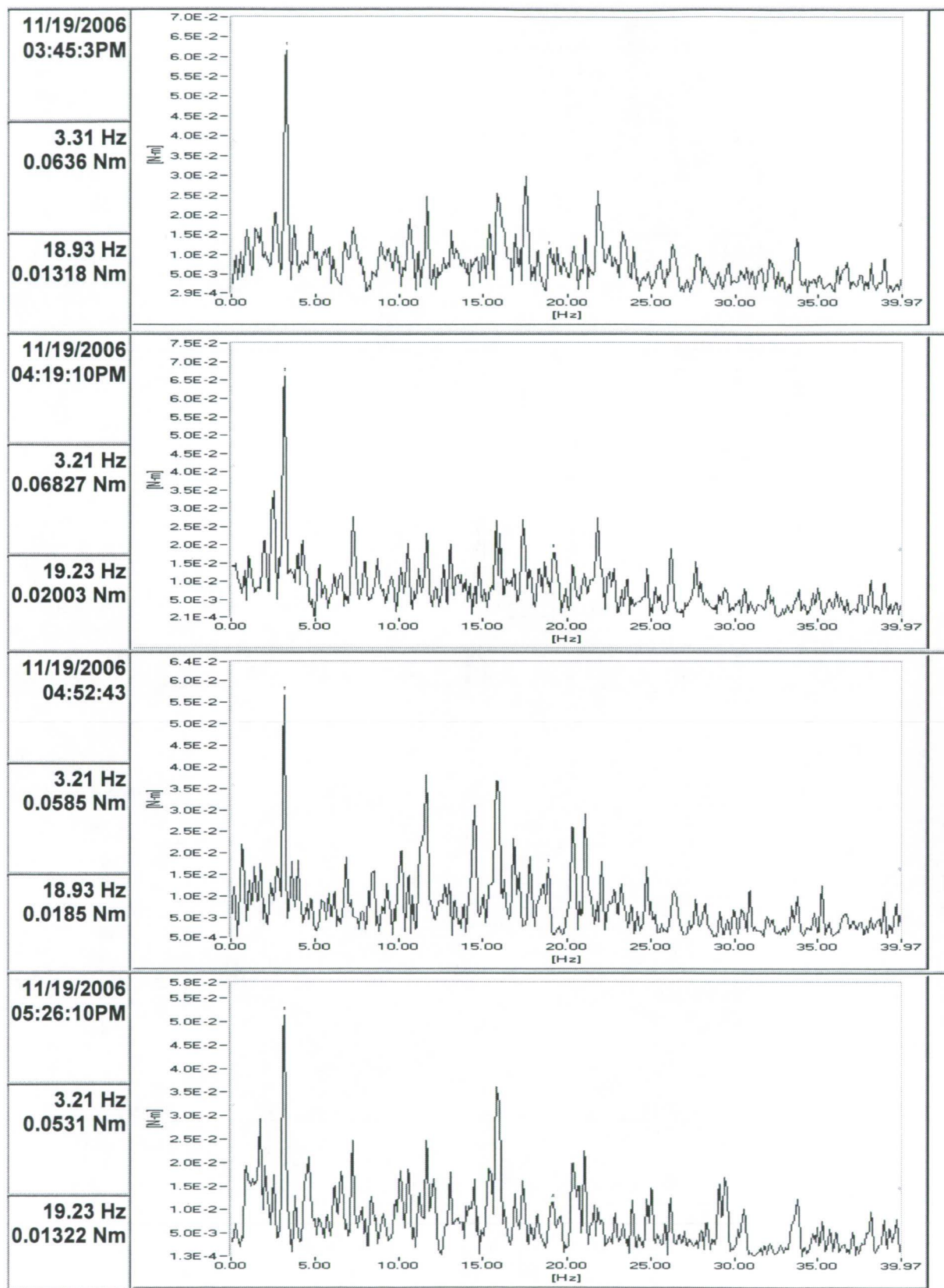
- Pad B Ox #1 Vibration analysis and Explorer data determined pump was in satisfactory condition
- Pad B Ox #2 Vibration and Explorer detected fluid whirl, however there were no severity levels set so pump was run until 100 hour mandatory inspection
 - If alarm levels had been set and recommendations made to inspect this pump earlier the rotor and bearings may have been saved
- Pad A Ox 2 Vibration analysis suggested there was fluid whirl on this pump, however Explorer determined this was not fluid whirl
- The problem was determined to be voltage sub-harmonics causing excessive vibration which appeared as fluid whirl to vibration analyst

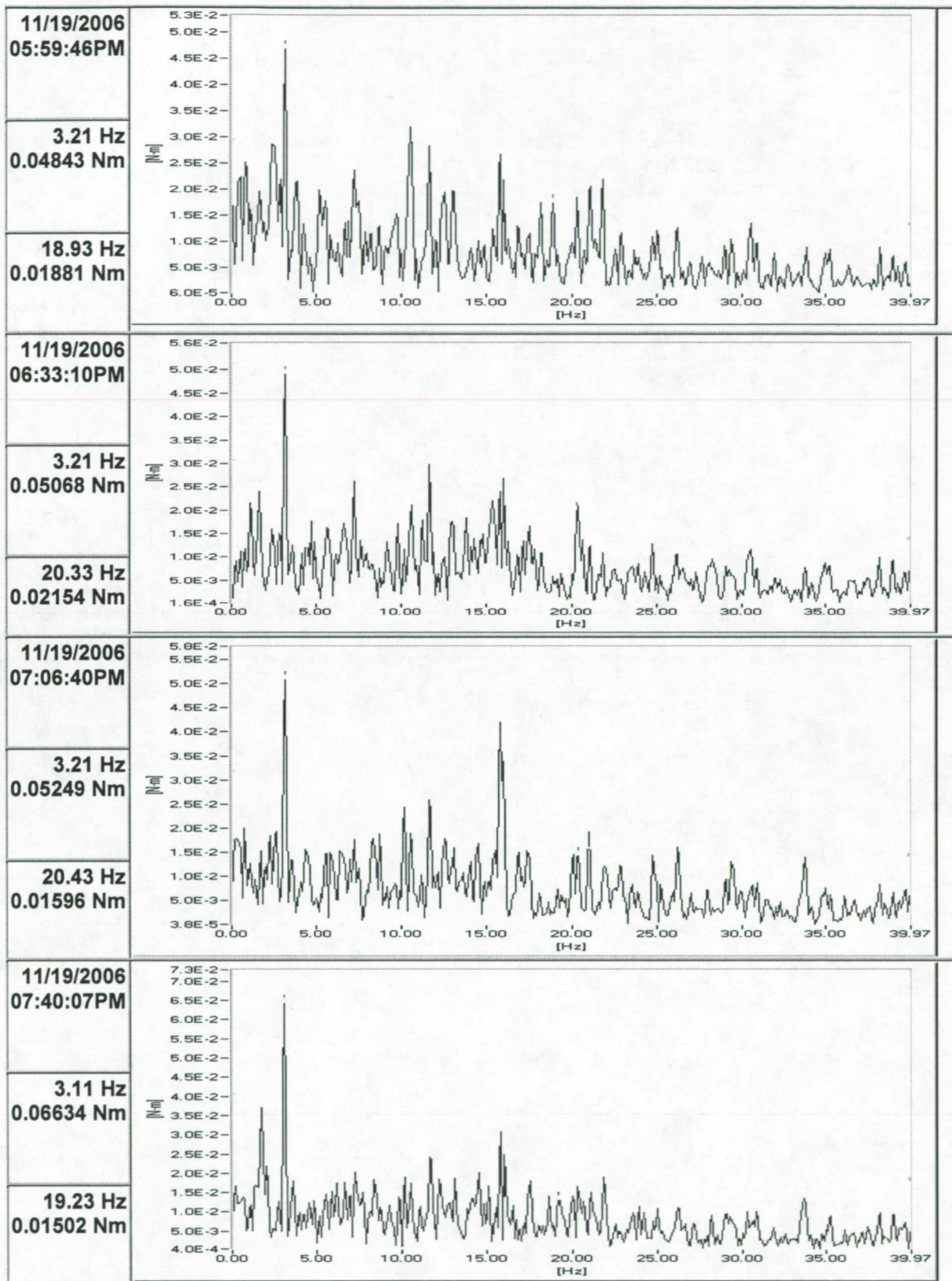


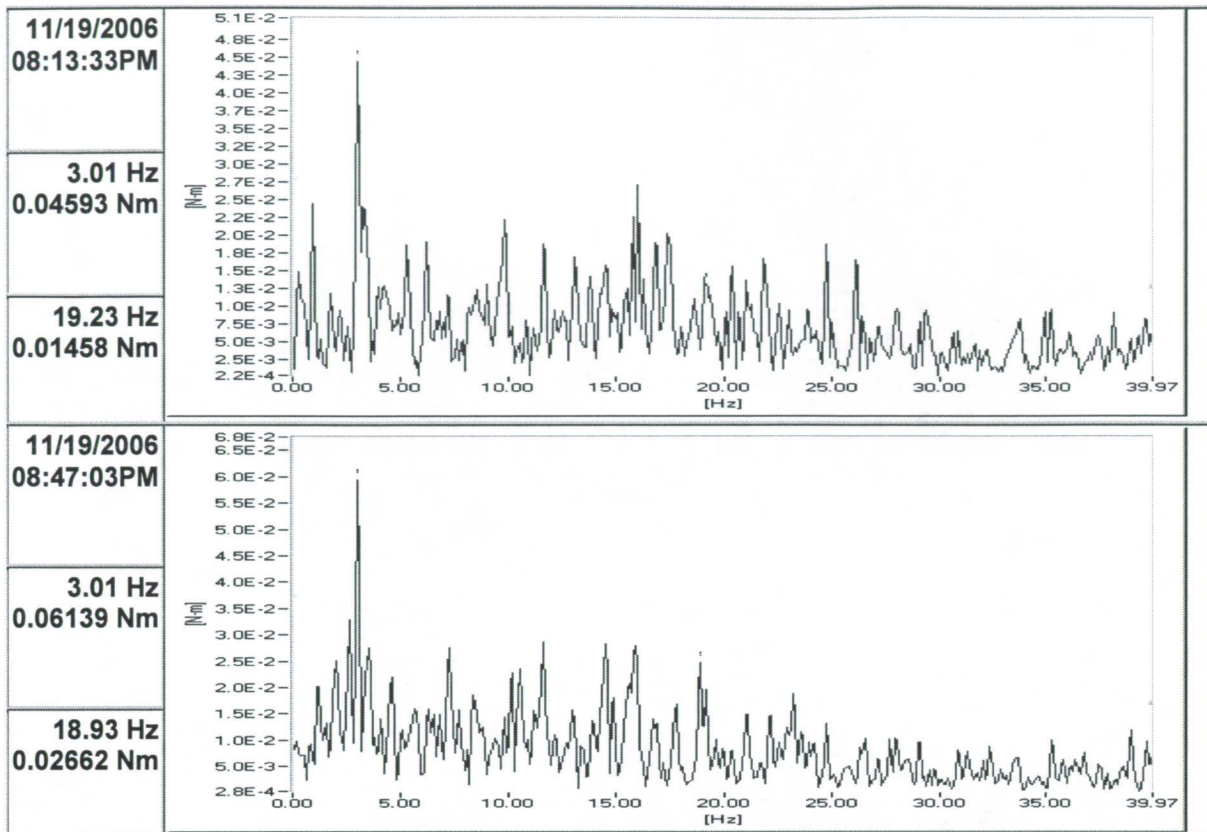


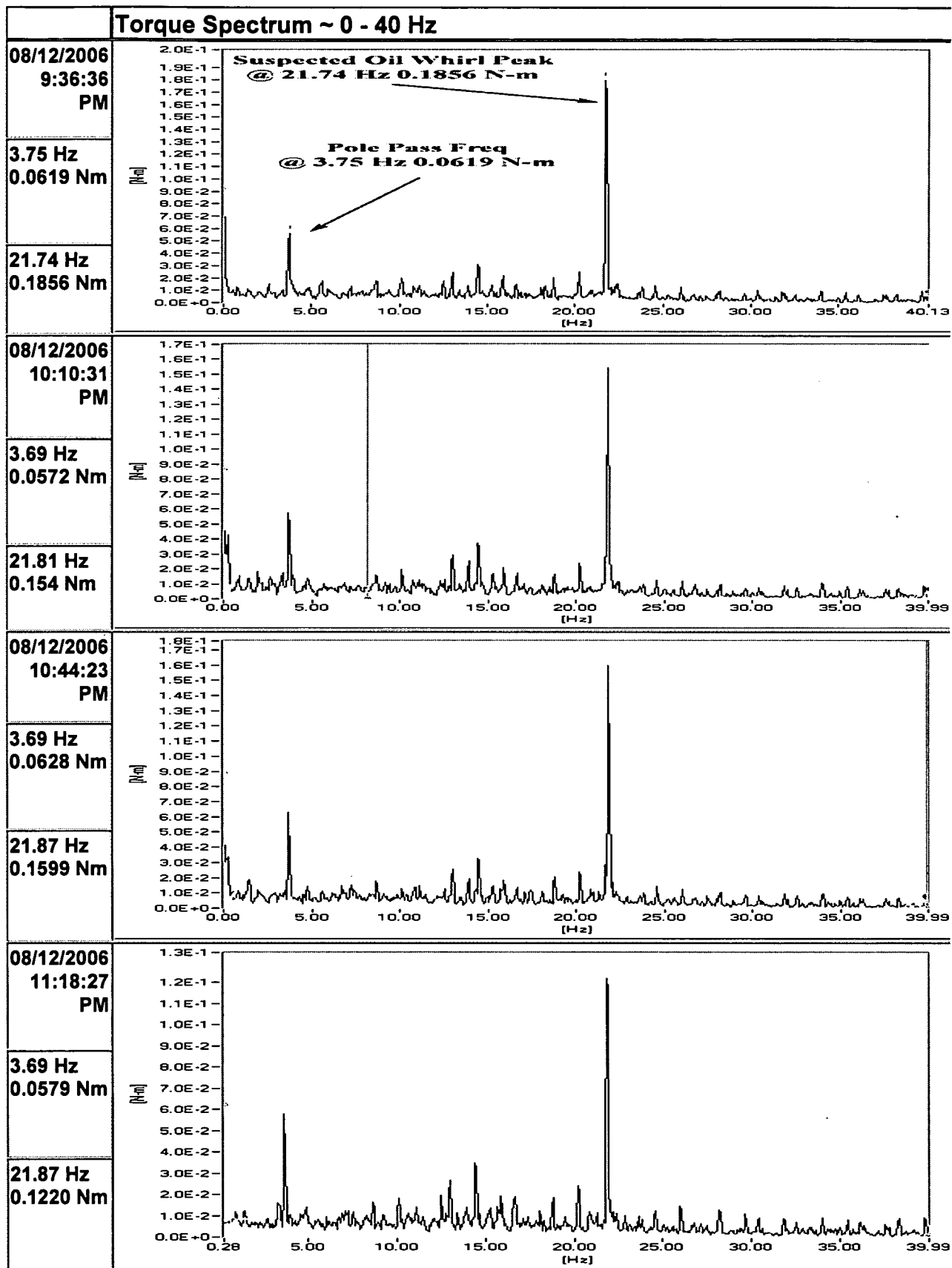


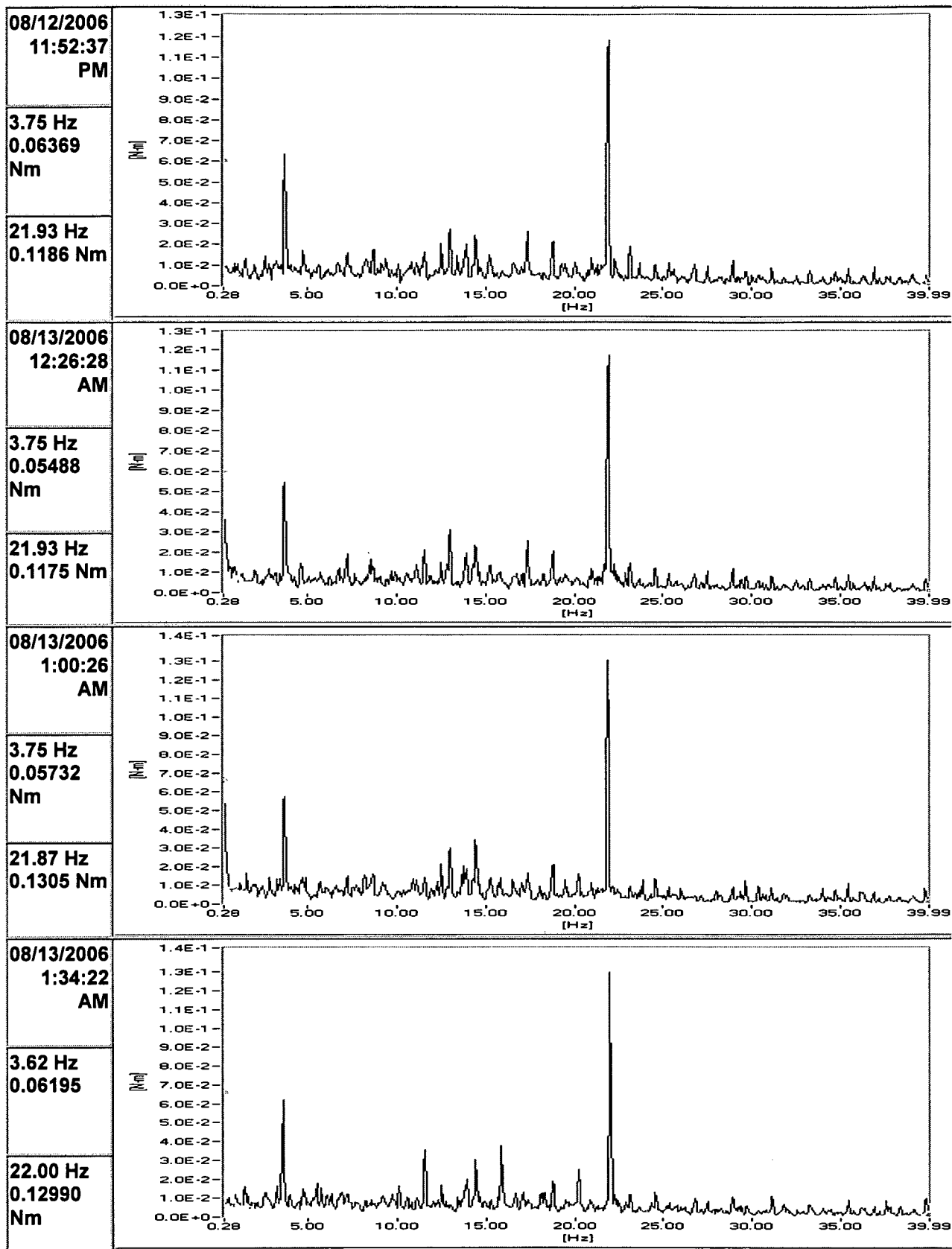


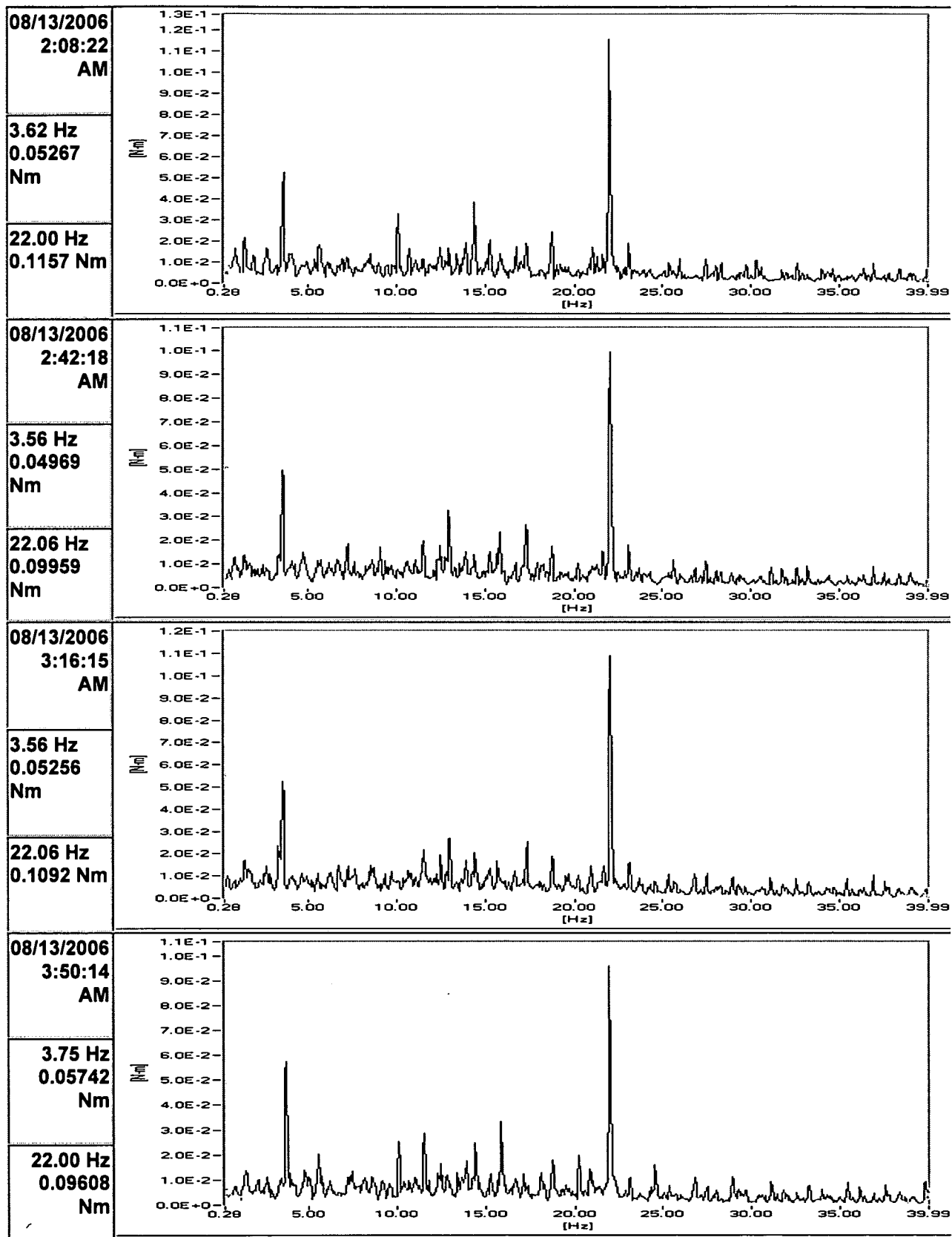


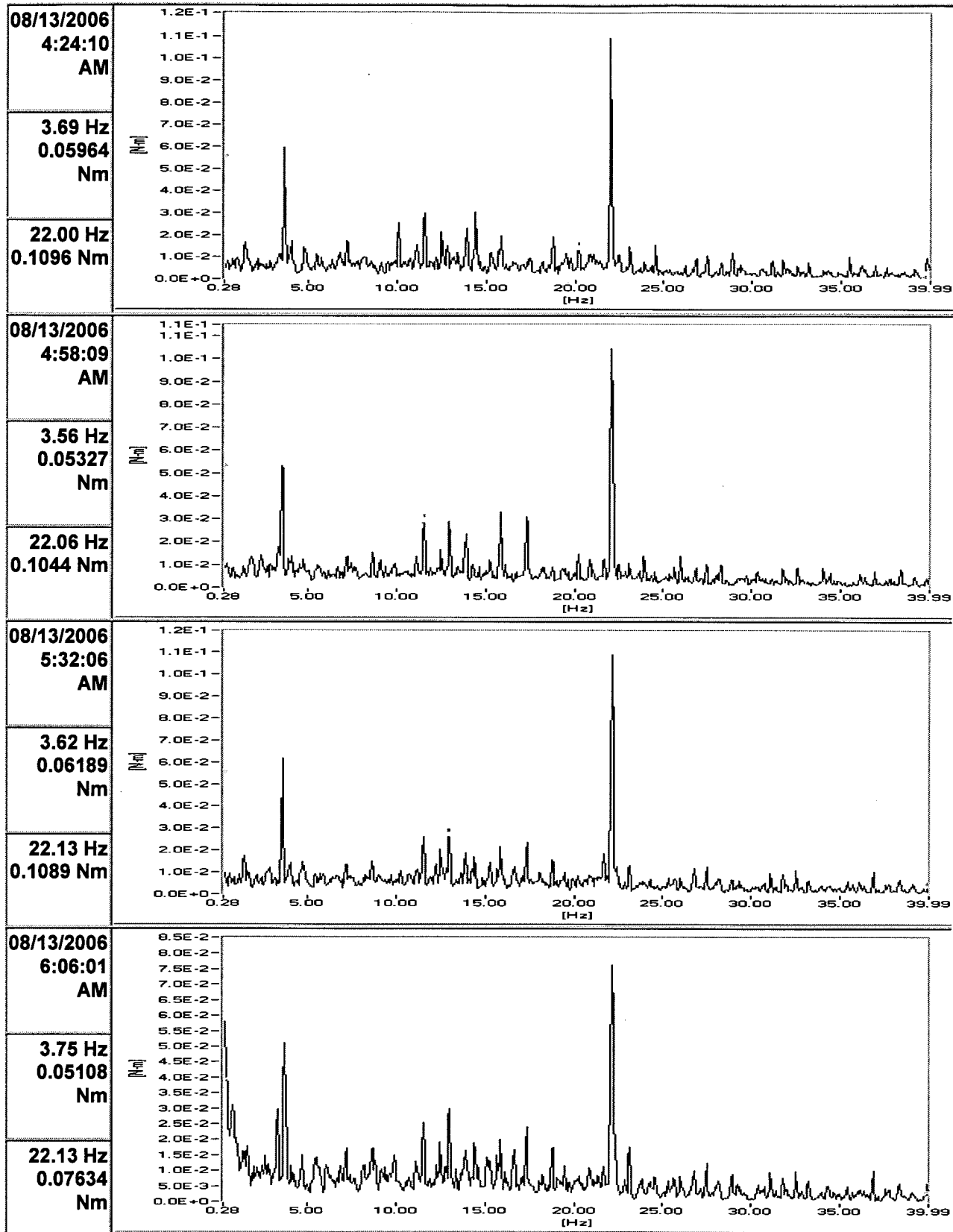


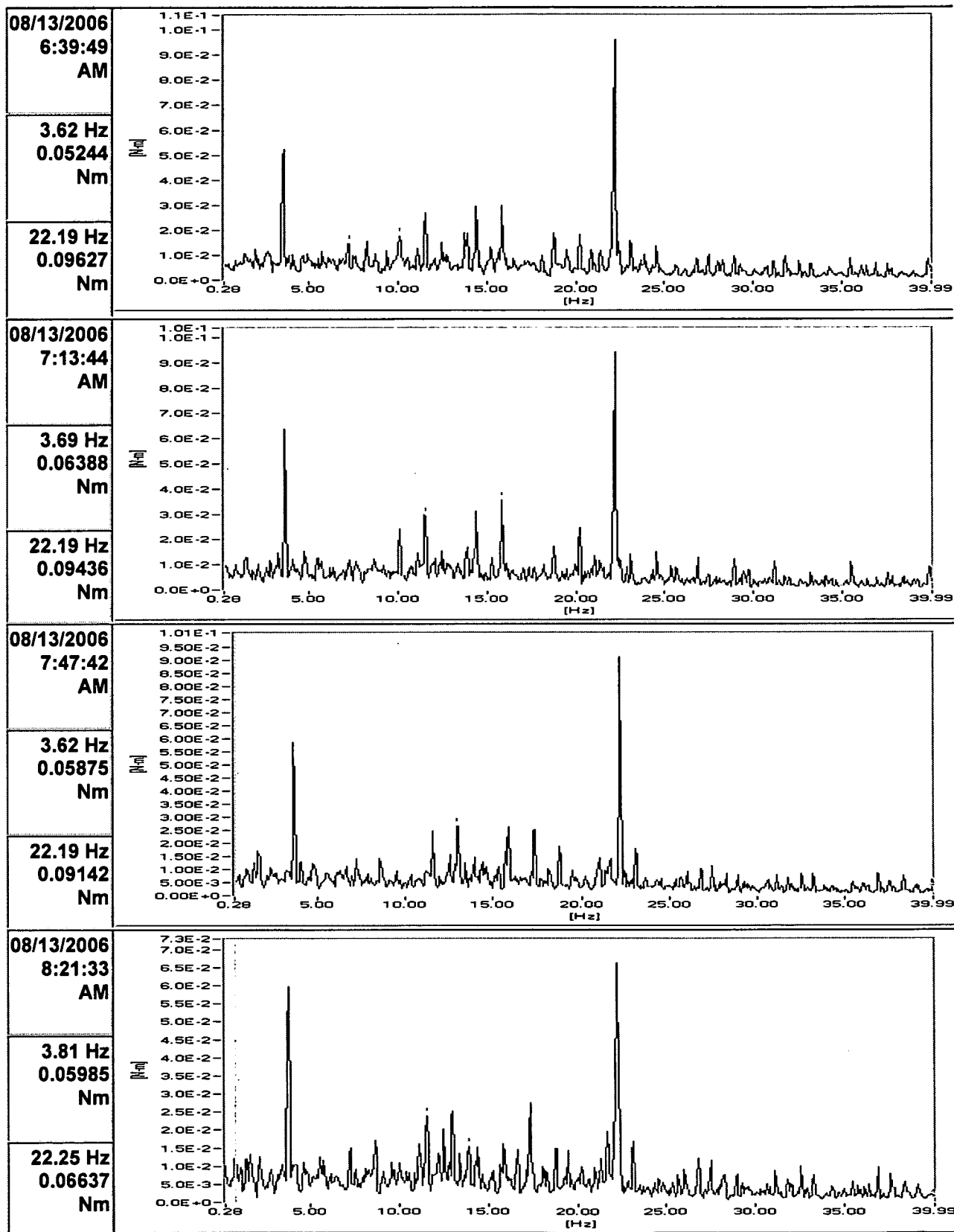


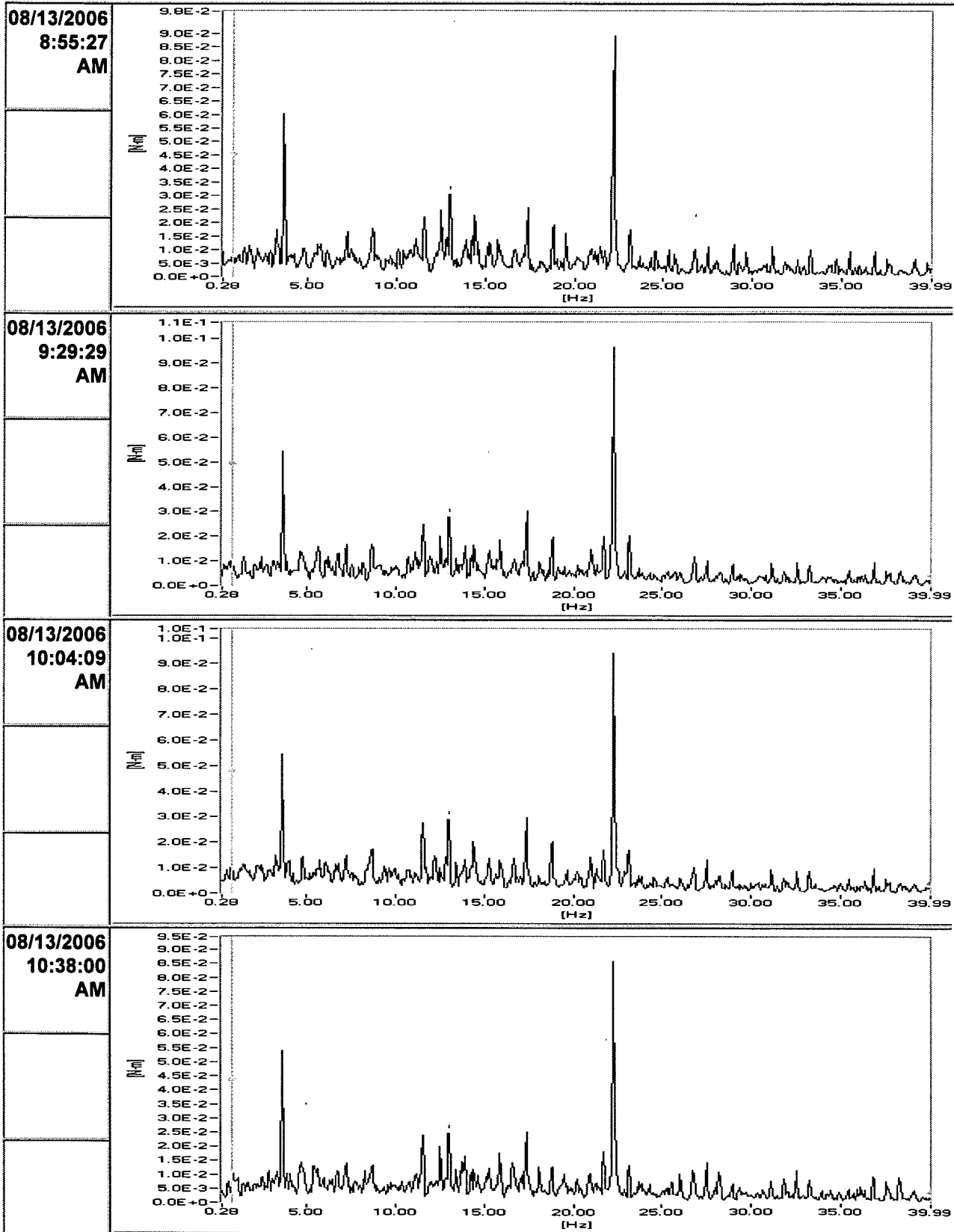


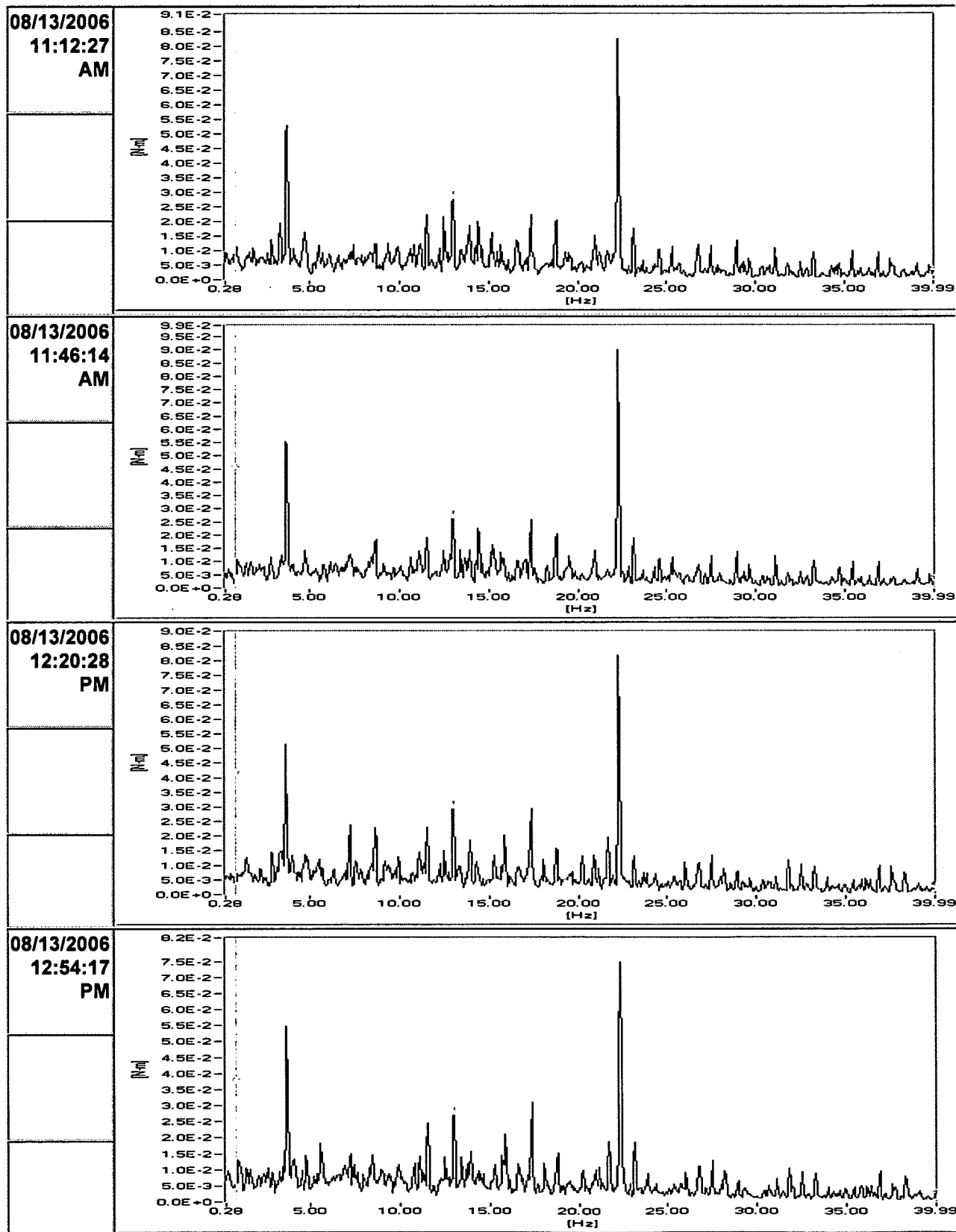


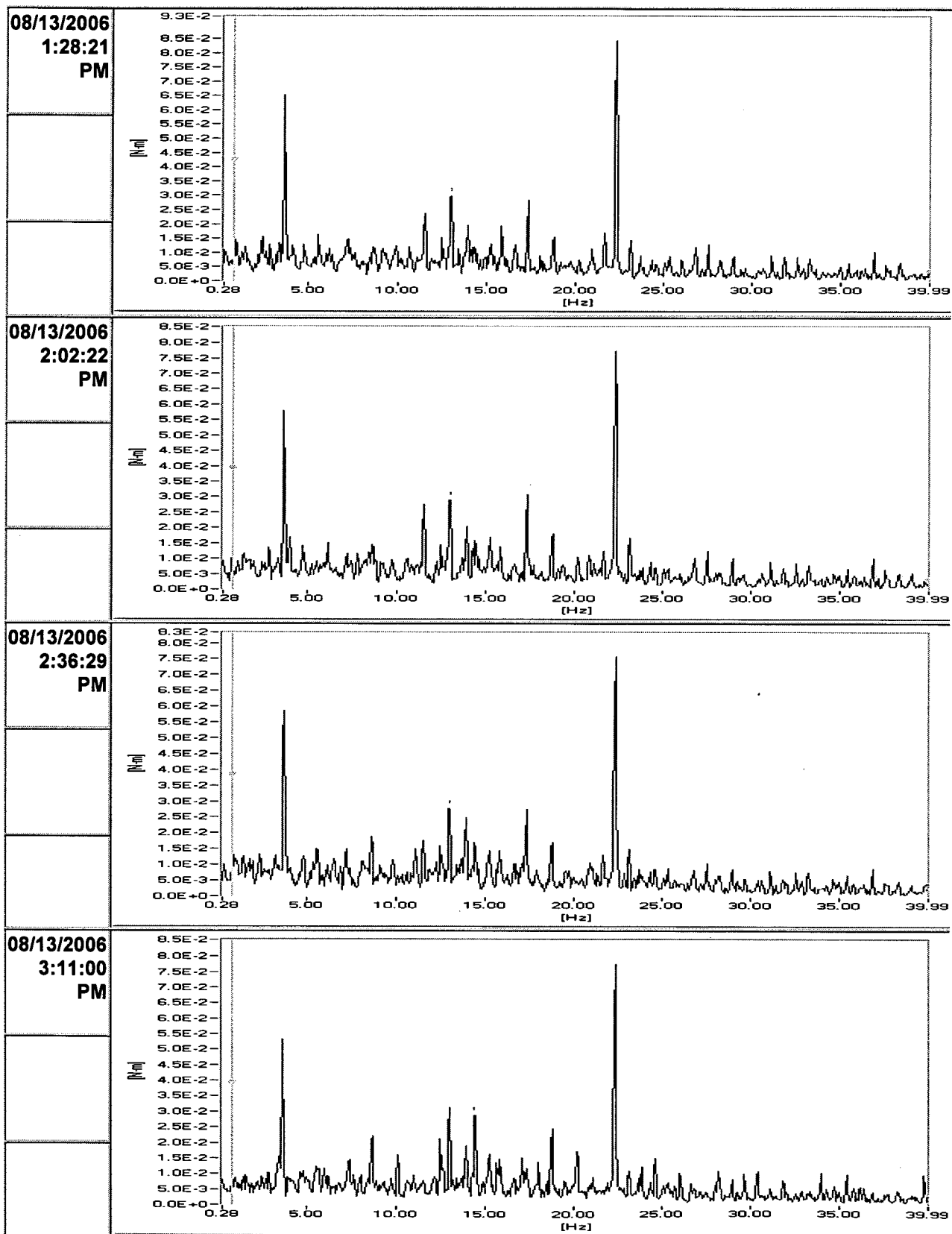


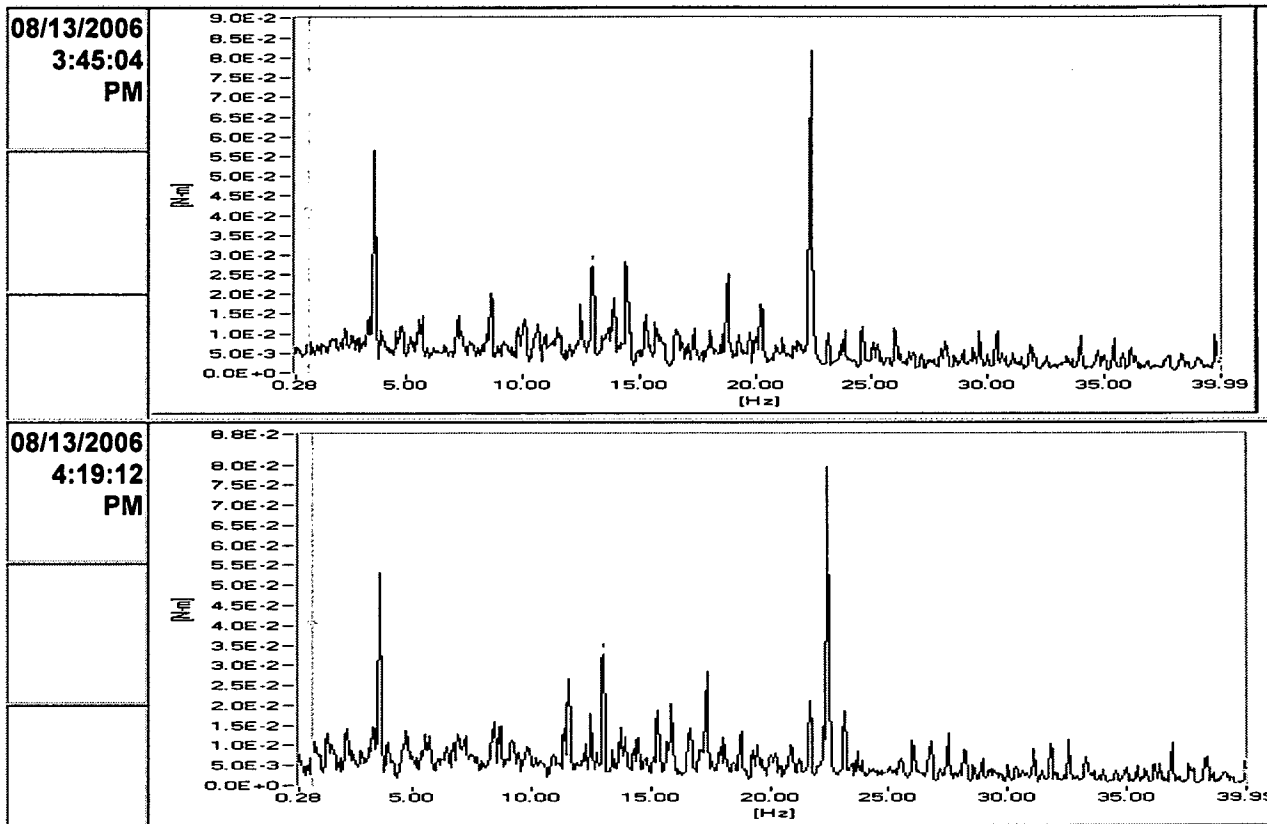












Condition Based vs. Time Based Maintenance

Case Study on Hypergolic Pumps

Lewis Gibson

August 2007

05/09/2007
Florida



United Space Alliance (USA)



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



United Space Alliance (USA)

Who are we?

- NASA's primary industry partner in human space operations, including the Space Shuttle and the International Space Station.

Three primary locations:

- Johnson Space Center, TX
- Marshall Space Flight Center, AL
- Kennedy Space Center, FL

- About 10,000 employees



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Predictive Maintenance Engineering Lab (PMEL)

Who are we?

- Predictive Maintenance for the Space Shuttle Program is based out of KSC and utilizes state-of-the-art technologies to monitor and trend equipment health.

Bearing Failure Analysis Thermography
Fluid Analysis Ultrasonic Noise Detection
Motor Circuit Evaluation Vibration Analysis

- Equipment condition trends are used to validate preventive maintenance cycles, reduce unplanned maintenance downtime, and improve machine reliability.
- PMEL Engineers perform acceptance and validation testing for new and rebuilt machinery thereby establishing the baseline for equipment health.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Shuttle Landing Facility (SLF)



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Orbiter Processing Facility (OPF)



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Vehicle Assembly Building (VAB)



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Going Vertical in the VAB



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



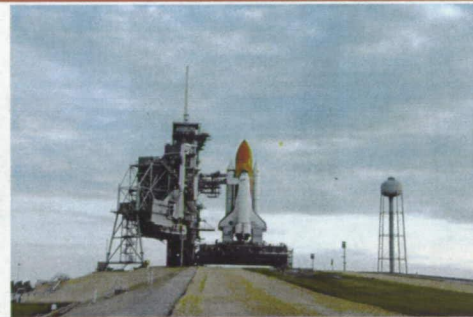
Launch Pads 39 A/B



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



STS-118



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



STS-117 June 2007



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.

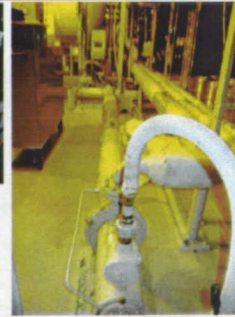


Test Set-up and Pad A pumps



Test set-up 7-22-2007 04:00

Pad A S00024 Operations STS-118



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00018-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Propellant Servicing



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



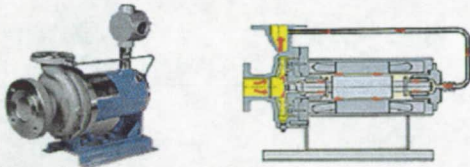
Pad Hyper Pump Testing

- PM cycle is very short, Oxidizer pumps must be inspected every 100-hours. Fuel pumps are on 300-Hour schedule.
- What are likely failure or historical failure modes
 - Journal bearing wear
 - Rotor stator contact and
 - Breaching jacket on stator
- PMEL began testing
 - Vibration test run in 1998 written into procedures in 2005.
 - Explorer first test run, August 2006.
- Operational Constraints
 - S.C.A.P.E. hazardous operations
 - all other processing at the Pad stops during S00024 operations.
- Test Setup Challenges
 - Monitor one pump at a time
 - timed loop acquisition

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



CRANE CHEMPUMP Series G



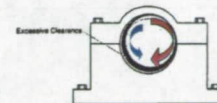
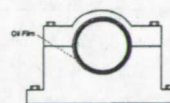
For normal clear fluid applications, Series G Chempumps are cooled and lubricated by the fluid being pumped, which flows through the circulating tube, into the rear of the rotor chamber, across the rear bearing, rotor, and front bearing, and then back into the main pumped stream through small holes provided in the rear of the impeller in the suction area.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Journal Bearings

Normal Bearing



Showing Excessive Clearance

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Causes of Fluid Whirl

- Poor bearing design
- Lightly loaded machine
- Change in fluid viscosity
- Bearing wear

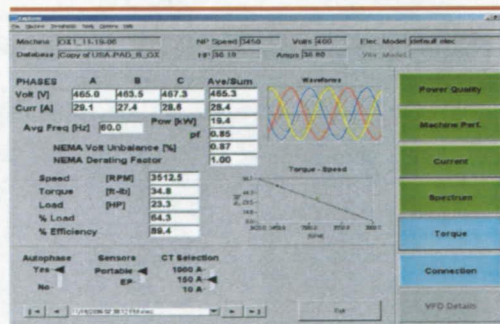
Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Pad B Ox #1

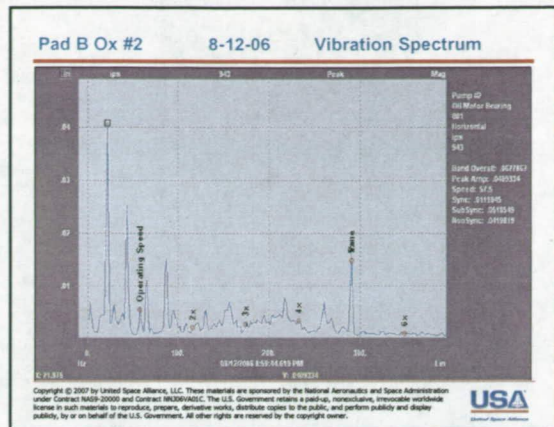
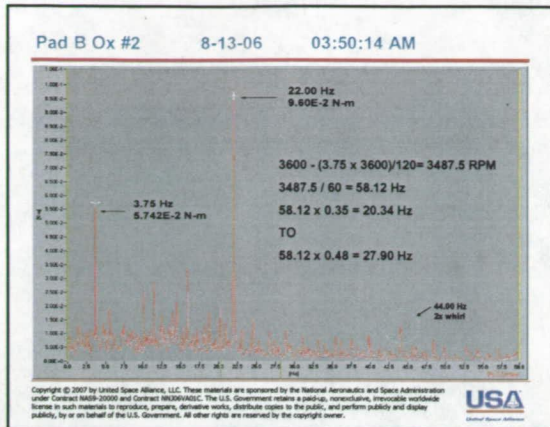
11-19-06

02:38:12 PM



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract M000000000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.





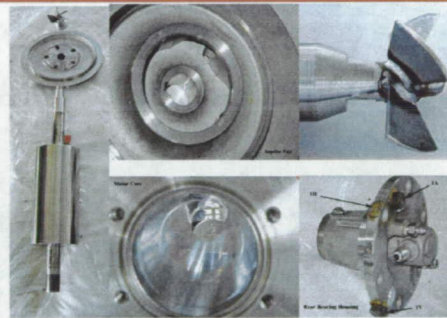
Summary of Ox #2 MCA analysis

- Vibration data indicated fluid whirl
- Explorer torque spectrum indicates possible fluid whirl
 - Possible severity indicator peak at 2x fluid whirl
- Unknown peak at 38Hz in current spectrum may be an alternative method of detecting whirl. (60 – 38 = 22)
- Eccentricity peaks at mechanical frequency times number of rotor bars is possible
 - Fmax was set to low to capture eccentricity peaks

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00020-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Pad B Ox #2 pump assembly



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00020-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



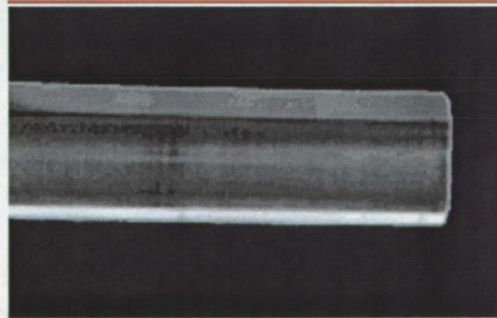
Front Journal Ox #1



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00020-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Rear Journal Ox #1



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00020-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N9306VA01C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved to the copyright owner.



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00061V041C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Manufactures Specifications		Ox Pump #1		Ox Pump #2	
		Front	Rear	Front	Rear
Journal	1.1833" - 1.1840"	1.183"	1.184"	1.184"	1.184"
Bearing	1.1880" - 1.1890"	1.189"	1.191"	1.193"	1.208"
Clear	.0048" - .0057"	0.006"	0.007"	0.009"	0.024"

Note: Manufactures maximum diametrical clearance is 0.014"

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract NRO06VA01C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Housing flange was warped about 0.020" causing the rear journal to contact the housing thereby resulting in excessive wear of the bearing.



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract NN06VIA21C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



- Pad B Ox 2 was disassembled and showed significant wear on the rear bearing and also had significant rotor rub

- If condition based maintenance were used it would have been possible to salvage the rotor and bearing, if the pump was removed from service earlier

- Pad B Ox 1 disassembly showed no abnormal wear
- With condition monitoring this pump could have remained in service and not been disassembled
- This pump had considerable remaining useful life (RUL) which was wasted when it was disassembled
- Re-assembly may introduce new problems into this pump

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract NKK06VNA02C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, in or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Machine: 333.7 NP Speed: 1450 Vph: 400 Elec. Model: Default elec.
 Database: Fock_Combi_038 Vph: 380 Angle: 30.00

PHASES

	A	B	C	Ave/Sum
Volt [V]	460.6	460.6	460.6	460.6
Cur [A]	30.2	29.4	30.0	29.9
				20.6
				0.38
				0.46
				1.00

Avg Freq [Hz]: 60.0 Pow [W]: pr

NEMA Volt Unbalance [%]: 0.46
 NEMA Derating Factor: 1.00

Speed [RPM]: 3488.4
 Torque [N·m]: 38.8
 Load [HP]: 24.4
 % Load: 67.5
 % Efficiency: 86.5

Autophase: Yes Sensors: Portable CT Selection: 1000 A
 No: EP 16 A

Waveforms

Torque - Speed

Power Quality

Machine Perf.

Current

Spectrum

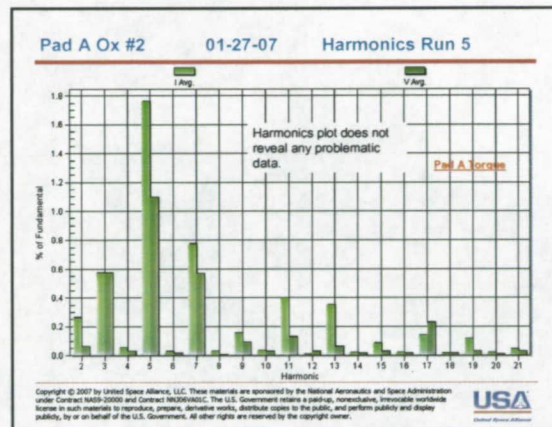
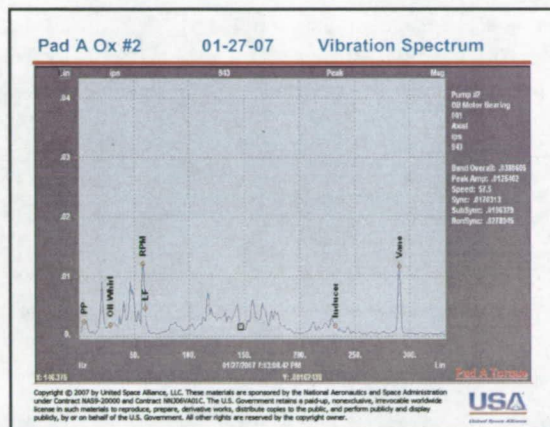
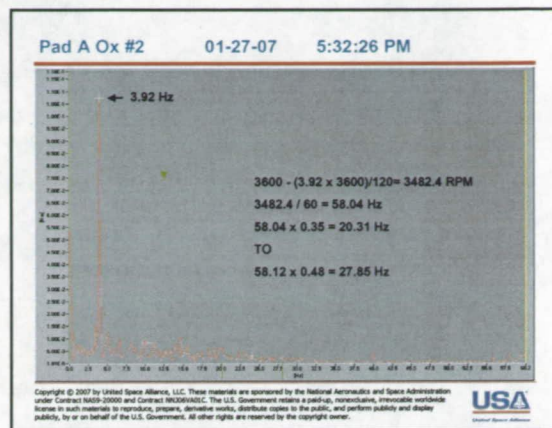
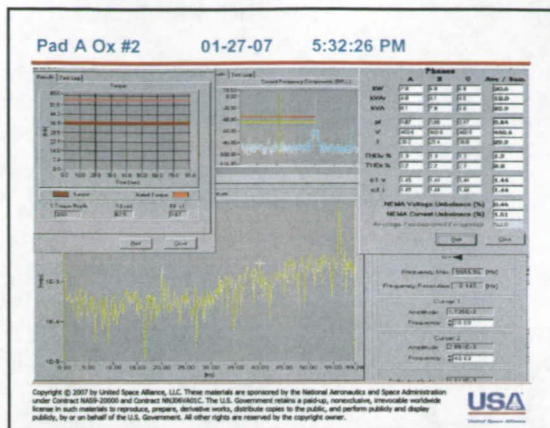
Torque

Connection

VFD Controls

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract NRO06VAD1C. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, in or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.





Preventative Maintenance (PM)

- **Preventative Maintenance:** time-based tasks including inspection, service and/or replacement.
 - Established cycle based on average statistical data, anticipated lifetime, or manageable impact from temporary loss of asset.
- PM may be invasive, requiring an outage and disassembly for visual inspection and/or overhaul/replacement regardless of condition.
 - The intervals between specific Preventive Maintenance tasks are based on average life or risk assessment.
- A PM program can be cost effective when equipment operation is consistent, average life is predictable within a reasonable span, failures are well understood and manageable, and useful failure statistics are available.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.

Predictive (PdM) or Condition Based Maintenance (CBM)

- **PdM/CBM:** Maintenance action based on actual condition obtained from in-situ, non-invasive tests, operating and condition measurements.
 - Condition Based Maintenance has proven capable of identifying faults early enough to minimize the impact of:
 - operational interruptions
 - avoid expensive failures
 - including collateral damage
 - significantly reduce the cost of maintenance.
- Some potential failures, such as fatigue, are not easily detected with condition measurements.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.

Criteria for Applying CBM

Preliminary Questions:

Does the technology monitor a specific failure mode?
Is it probable that this failure mode will occur during the lifetime of the equipment?

Application Criteria:

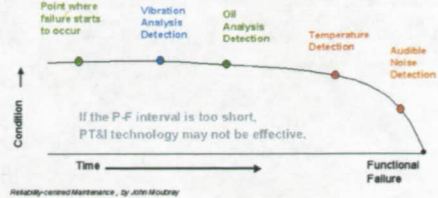
Changes in specific equipment parameters must correlate to corresponding failure mode.
The parameter must be accurately and consistently measurable.
There must be enough time between potential and functional failure to allow for corrective action.

The monitoring interval must be shorter than the P-F interval.
Multiple monitoring points during the P-F interval increases confidence in the diagnosis.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



P-F curve

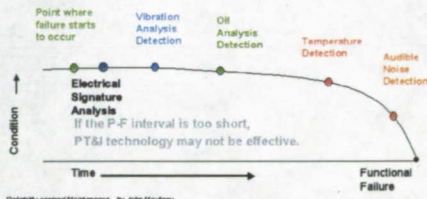


Reliability-centered Maintenance, by John Moubray

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



P-F curve (modified)



Reliability-centered Maintenance, by John Moubray

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



On-Line Monitoring

- Objective: Improve on-line monitoring of Oxidizer and Fuel motors during S00024 operations.
- Need: Because bearing wear out can lead to catastrophic failure.
- Impact: provide early warning of impending failures which can be used for tactical decision making. With Explorer and Vibration data subtle changes can be trended and disaster can be avoided.
 - Maintenance decisions can be optimized by including condition based information to determine overhaul and planned replacement schedules.
 - Operational decisions can be improved by understanding and relating machinery condition to operational load and predicted time to failure.
 - The value of these On Line Monitoring techniques will be increased availability and reduced maintenance costs.

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Fault Detection

- Issues: What fault modes are detectable with currently installed instrumentation?
 - Voltage/Current balance
 - Loss of power
- What can be detected with Vibration Analysis and Explorer?
 - Rotor rub
 - Whirl (a.k.a. Oil Whirl)
 - Impeller issues
 - Resonance issues
 - Rotor faults (Porosity, broken bars, etc...)
 - Eccentricity (Static and Dynamic)
 - Electrical Faults and other hidden problems (power quality)

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Summary

- Pad B Ox #1 Vibration analysis and Explorer data determined pump was in satisfactory condition
- Pad B Ox #2 Vibration and Explorer detected fluid whirl, however there were no severity levels set so pump was run until 100 hour mandatory inspection
 - If alarm levels had been set and recommendations made to inspect this pump earlier the rotor and bearings may have been saved
- Pad A Ox 2 Vibration analysis suggested there was fluid whirl on this pump, however Explorer determined this was not fluid whirl, the problem was determined to be voltage sub-harmonics causing excessive vibration which appeared as fluid whirl to vibration analyst

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS9-20000 and Contract N00019-00-2-0000. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Summary of Fluid Whirl Detection

- Explorer can detect it
 - Like Vibration the fluid whirl peak ranges from approximately 35 to 48 percent of the mechanical frequency or RPM
 - Potential of severity by comparison with Fpp levels or if 2x peak is present
 - Eccentricity peaks at mechanical frequency times number of rotor bars is possible
 - Fmax should have been set higher to capture eccentricity peaks
- Vibration should be cautious with interpretation, could be voltage issues
- Advance data analysis may be required
- Use of multiple technologies is helpful to validate results
 - Need to correlate Vibration and Explorer data as soon as operation is completed and data retrieved and analyzed
 - Process data (flow rate, pressure, temperature, etc.) could also be recorded and trended to help validate data

Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS46-20000 and Contract NAS46-00002. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Questions???



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS46-20000 and Contract NAS46-00002. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



Backup



Copyright © 2007 by United Space Alliance, LLC. These materials are sponsored by the National Aeronautics and Space Administration under Contract NAS46-20000 and Contract NAS46-00002. The U.S. Government retains a paid-up, nonexclusive, irrevocable worldwide license in such materials to reproduce, prepare, derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the U.S. Government. All other rights are reserved by the copyright owner.



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 08-01-2007			2. REPORT TYPE Power Point		3. DATES COVERED (From - To) 8-13-2006 to 11-30-2006	
4. TITLE AND SUBTITLE Condition Vs. Time Based Maintenance					5a. CONTRACT NUMBER	
					5b. GRANT NUMBER	
					5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Lewis Gibson					5d. PROJECT NUMBER J0055T00AE	
					5e. TASK NUMBER	
					5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United Space Alliance Predictive Maintenance Engineering USK-514					8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA, KSC					10. SPONSORING/MONITOR'S ACRONYM(S)	
					11. SPONSORING/MONITORING REPORT NUMBER	
12. DISTRIBUTION/AVAILABILITY STATEMENT						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT Two Pad 39B Ox pumps were monitored with the Baker Instruments Explorer Motor tester. Using the torque spectrum it was determined that Ox pump #2 had a significant peak at a frequency, which indicated lubricant fluid whirl. Similar testing on Ox pump #1 didn't indicate this peak, an indication that this pump was in good mechanical condition. Subsequent disassembly of both motors validated these findings. Ox pump #2 rear bearing showed significant wear, the front bearing showed little wear. Ox pump #1 was still within manufacturers tolerances.						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)	